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Volume II

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RETROFIT EXPERIENCE IN U.S. MULTIFAMILY BUILDINGS: ENERGY SAVINGS, COSTS, AND ECONOMICS†

Volume II

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TABLE OF CONTENTS

VOLUME I

VOLUME II

APPENDIX A: MULTIFAMILY 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. Tables A-1, A-2, and A-3 contain information on retrofitted U.S. buildings; Tables A-4, A-5, and A-6 show results for European buildings.† Each retrofit is uniquely identified by a label. (If more than one separately analyzed retrofit is carried out at a property, the same label, appended with an asterisk(s), is used for each successive retrofit package(s).)

The following terms and abbreviations are used in the tables:

TABLES A-1 and A-4:

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, *X*=Other (coal, district heating).

Building Type: *HR*=high-rise, *LR*=low-rise (4 stories or less), *CO*=combination of types.

Meter Type: *IM*=individually metered, *MM*=master-metered.

Ownership: *PR*=privately owned housing, *PU*=public housing (managed by a local housing authority).

Number of Occupants Pre: The average number of occupants per dwelling unit before the retrofit.

Wall Type: *BR*=brick, *CB*=concrete block, *FR*=frame, *MA*=masonry.

No. of Glazing Layers: Number of glazing layers in windows prior to retrofit (averaged if number varies throughout building).

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).

TABLES A-2 and A-5:

End Uses: End uses included in consumption data: *A*=lighting and appliances (including air conditioning), *D*=domestic hot water, *F*=all end uses of space heat fuel, *H*=space heat, *L*=lighting, *W*=space heat and hot water.

Floor Area: Total or conditioned floor area per apartment, in ft^2.

† Results from European buildings will be discussed in a forthcoming LBL report.

Energy Use Data: All values are *per dwelling unit*; electricity use is reported as kWh/dwelling unit, consumption at fuel-heat projects is expressed in MBtu/dwelling unit (1 MBtu=10^6 Btu). Oil and gas consumption converted to MBtus using the following conversion factors: #2 oil=0.139 MBtu/gallon, #4 oil=0.145 MBtu/gallon, #6 oil=0.150 MBtu/gallon, gas=0.102 MBtu/ccf=0.100 MBtu/therm.

NAC: Weather-normalized annual consumption, for end uses coded as *A*, *D*, *F*, *L*, and *W*. End uses coded as *H* sometimes have space heat plus estimated domestic hot water consumption entered in this field.

Prediction Method: Description or complexity of audit prediction method: *HOUR*=building energy simulation program that computes building loads each hour, *MONT*=building energy simulation program that computes building loads each hour, *SSHL*=steady-state heat-loss engineering calculation, *EST*=estimate based on previous results for similar buildings.

Predicted Savings: Predicted percentage energy savings.

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

Analysis Method: *E*=regression of submetered end-use data (e.g., space heat), *F*=regression with fixed reference temperature (usually 65°F), *R*=regression (PRISM) with variable reference temperature, *S*=scaling of space heat data by annual or monthly HDD.

Confidence Level: *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.

HDD: Long-term average heating degree-days to base 65°F.

Heat System Type: *C*=central (one boiler room per project), *B*=building (one boiler room per building), *G*=group (one boiler room for a group of buildings, but not for whole project), *I*=individual (one heater per dwelling unit).

Heat Distribution Type: *D*=double-pipe steam, *S*=single-pipe steam, *W*=water,

Domestic Hot Water (DHW) Fuel: *E*=electricity, *G*=gas, *M*=mixed, *O*=oil, *X*=other.

TABLES A-3 and A-6:

Retrofit Measures: *CM*=computerized energy management system, *CR*=cooling system replacement, *CS*=cooling system retrofit, *CW*=caulk and weatherstrip, *DR*=door replacement, *DS*=storm doors, *HC*=heating controls, *HR*=heating system replacement, *HS*=heating system retrofit, *HX*=heat exchanger, *IA*=attic insulation, *ID*=duct insulation, *IF*=floor insulation, *IW*=wall insulation, *IX*=general insulation, *LC*=lighting controls, *LS*=lighting system retrofit, *MC*=metering change, *OM*=operations and maintenance, *PI*=pressurization/infiltration reduction (house doctoring), *SR*=structural renovation, *SW*=solar hot water, *T*=clock thermostat, *WH*=water-heating retrofit, *WM*=window management, *WR*=window replacement.

Heat System Measures: *BSH*=base central heating and supplemental elec. heat by apartment, *BTC*=boiler temperature/pressure control, *CEC*=economizer (non-condensing and condensing), *CLT*=automatic setback or clock thermostat, *CUT*=high limit outdoor thermostat, *EDH*=extended draft hood, *EMC*=energy mangement system with microcomputer, *EMR*=remote computerized HVAC control, *EWB*=European water balancing, *FD*=full furnace derating, *FEB*=addition of front-end boiler, *HES*=non-condensing heat extractor, *HEL*=condensing heat extractor, *HRE*=heating plant replacement with high-efficiency boilers/furnace, *HRM*=replace heating plant with modular boilers, *HWR*=hot water boiler replacement, *IHW*=insulating water heater blanket, *IID*=intermittent ignition device, *IPI*=insulation on hot water pipes, *LFS*=low-flow showerhead, *MSB*=Minneapolis steam balancing, *OMC*=operations and maintenance on heating controls, *OMP*=operations and maintenance on heating plant, *RES*=outdoor reset controls, *RHB*=flame retention head burner, *SET*=hot water temperature setback, *SHT*=separate DHW heater, *SHW*=steam to hot water conversion, *STR*=steam trap replacement, *TRV*=thermostatic radiator vents, *TU*=furnace tune-up, *TUR*=turbolators, *VDE*=electronic vent dampers, *VDT*=thermal vent dampers, *VR*=vent restrictor.

Economic Indicators: Retrofit costs and energy prices are in 1987 $/dwelling unit; maintenance costs are in nominal $ per apartment.

Simple Payback Time: The period required for the undiscounted cumulative value of future energy savings (at today's energy prices) 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.

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. U.S. buildings data base: building characteristics.

BLDG. LABEL	LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
E012	NEW YORK	NY	159	1	1965	HR	MM	PU	2.8	MA					
E019.1	SEATTLE	WA	21	1	1963	LR	IM	PR	2.0	FR		8	30	11	11
E019.2	SEATTLE	WA	17	1	1928	LR	IM	PR	1.4	FR		11	11	0	0
E019.3	SEATTLE	WA	21	1	1968	LR	IM	PR	1.5	FR		11	11	11	11
E021	NEW YORK CITY	NY	1666	2	1977	HR	MM	PR		MA	2.0	15	15	8	8
E022	NEW YORK	NY	2820	15		HR	MM	PR	2.3						
E025	NEWARK	DE	3	1	1981	LR	IM	PR		FR	2.0	19	19	11	11
E026.1	NYC	NY	100	1	1955	HR	MM	PR							
E026.2	NYC	NY	800	39	1965	LR	MM	PR							
E026.3	NYC	NY	234	2	1955	HR	MM	PR							
E027.10	HOOD RIVER	OR	7	2	1975	LR	IM	PR	1.8	FR	1.0	14	49	11	11
E027.11	HOOD RIVER	OR	8	2	1972	LR	IM	PR	1.6	FR	1.0	19	39	11	11
E027.13	HOOD RIVER	OR	8	2	1977	LR	IM	PR	1.8	FR	2.0	30	39	11	11
E027.14	HOOD RIVER	OR	9	1	1974	LR	IM	PR	1.2	FR	1.0	6	49	11	11
E027.15	HOOD RIVER	OR	10	1	1973	LR	IM	PR	1.2	FR	1.0	11	49	11	11
E027.16	HOOD RIVER	OR	12	2	1976	LR	IM	PR	1.4	FR	2.0	27	49	11	11
E027.17	HOOD RIVER	OR	12	1	1964	LR	IM	PR	1.3	FR	1.0	15	49	11	11
E027.18	HOOD RIVER	OR	16	1	1910	LR	IM	PR	1.5	FR	1.0	0	49	0	18
E027.19	HOOD RIVER	OR	27	1	1978	LR	IM	PR	1.0	FR	2.0	22	22	19	19
E027.20	HOOD RIVER	OR	33	8	1973	LR	IM	PR	2.4	FR	1.0	12	12	12	12
E027.21	HOOD RIVER	OR	48	8	1970	LR	IM	PR	2.6	FR	1.5	15	45	10	11
E027.22	HOOD RIVER	OR	48	10	1969	LR	IM	PR	2.2	FR	1.0	15	49	11	11
E027.23	HOOD RIVER	OR	48	7	1981	LR	IM	PR	2.1	FR	2.0	20	49	19	19
E027.24	HOOD RIVER	OR	56	6	1978	LR	IM	PR	1.6	FR	2.0	14	49	11	11
E027.3	HOOD RIVER	OR	4	1	1979	LR	IM	PR	1.3	FR	2.0	14	49	11	11
E027.4	HOOD RIVER	OR	4	1	1962	LR	IM	PR	1.8	FR	1.0	10	49	11	11
E027.5	HOOD RIVER	OR	4	1	1977	LR	IM	PR	2.7	FR	2.0	23	23	11	11
E027.6	HOOD RIVER	OR	4	1	1952	LR	IM	PR	2.0	MA	1.0	7	7	0	0
E027.7	HOOD RIVER	OR	4	1	1974	LR	IM	PR	2.0	FR	2.0	9	49	11	11
E027.8	HOOD RIVER	OR	7	1	1930	LR	IM	PR	1.2	FR	1.9	38	42	2	11
E027.9	HOOD RIVER	OR	6	1	1915	LR	IM	PR	1.3	FR	1.0	14	42	1	12
E028.1	SEATTLE	WA	7	1	1973	LR	IM	PR		FR					
E028.10	SEATTLE	WA	8	1	1960	LR	IM	PR		FR			22		
E028.11	SEATTLE	WA	19	1	1968	LR	IM	PR		FR					
E028.12	SEATTLE	WA	15	1	1968	LR	IM	PR		FR					
E028.13	SEATTLE	WA	6	1	1927	LR	IM	PR		FR			38		
E028.14	SEATTLE	WA	10	1	1967	LR	IM	PR		FR					
E028.15	SEATTLE	WA	14	1	1964	LR	IM	PR		FR					
E028.2	SEATTLE	WA	20	1	1958	LR	IM	PR		FR					
E028.3	SEATTLE	WA	8	1	1921	LR	IM	PR		FR			38		11

Table A-1. U.S. buildings data base: building characteristics (continued).

BLDG. LABEL	LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
E028.4	SEATTLE	WA	13	1	1957	LR	IM	PR		FR					
E028.5	SEATTLE	WA	12	1	1971	LR	IM	PR		FR					
E028.6	SEATTLE	WA	25	1	1950	LR	IM	PR		CB			30		11
E028.7	SEATTLE	WA	23	1	1920	LR	IM	PR		FR			38		
E028.8	SEATTLE	WA	12	1	1962	LR	IM	PR		FR					
E028.9	SEATTLE	WA	13	1	1957	LR	IM	PR		FR					
E029.1	DENVER	CO	100	1	1979	HR	MM	PU	1.0	CB	2.0	12	12	17	17
E029.1A	DENVER	CO	100	1	1979	HR	MM	PU	1.0	CB	2.0	12	12	17	17
G031.1	CHICAGO	IL	19	1	1910	LR	MM	PR		MA	2.0	0	40		
G031.2	CHICAGO	IL	22	1	1910	LR	MM	PR		MA	2.0	0	40		
G031.3	CHICAGO	IL	25	1	1910	LR	MM	PR		MA	1.0	0	40		
G031.4	CHICAGO	IL	7	1	1910	LR	MM	PR		MA	2.0	12	12		
G031.5	CHICAGO	IL	6	1	1910	LR	MM	PR		MA	1.0	0	40		
G031.6	CHICAGO	IL	6	1	1910	LR	MM	PR		MA	1.8	40	40		
G031.7	CHICAGO	IL	4	1	1910	LR	MM	PR		MA	2.0	40	40		
G031.8	CHICAGO	IL	13	1	1910	LR	MM	PR		MA	1.7	40	40		
G032	NEWARK	NJ	530	12	1940	LR	MM	PU		MA					
G035.1	SAN FRANCISCO	CA	772	91	1942	LR	MM	PU	3.7	CB		0	19		
G035.11	SAN FRANCISCO	CA	107	5	1970	HR	MM	PU		CB					
G035.12	SAN FRANCISCO	CA	108	1	1972	HR	MM	PU		CB					
G035.13	SAN FRANCISCO	CA	22	1	1971	LR	MM	PU		FR					
G035.14	SAN FRANCISCO	CA	40	1	1971	LR	MM	PU		FR					
G035.15	SAN FRANCISCO	CA	75	1	1973	HR	MM	PU		MA					
G035.16	SAN FRANCISCO	CA	36	1	1971	LR	MM	PU		FR					
G035.2	SAN FRANCISCO	CA	469	38	1942	LR	MM	PU	3.3	CB		0	19		
G035.4	SAN FRANCISCO	CA	258	41	1962	LR	MM	PU	4.8	FR		0	19		
G035.5	SAN FRANCISCO	CA	158	24	1956	LR	MM	PU	4.0	FR		0	19		
G035.6	SAN FRANCISCO	CA	170	10	1963	LR	MM	PU	2.6	FR		0	19		
G036.1	HIGHTTOWN	NJ	32	1	1965	LR	MM	PR	2.0	MA	1.0	30	30	14	14
G036.2	HIGHTTOWN	NJ	32	1	1965	LR	MM	PR	2.0	MA	1.0	30	30	14	14
G036.3	HIGHTTOWN	NJ	32	1	1965	LR	MM	PR	2.0	MA	1.0	30	30	14	14
G036.4	HIGHTTOWN	NJ	16	1	1965	LR	MM	PR	2.0	MA	1.0	30	30	14	14
G036.5	HIGHTTOWN	NJ	16	1	1965	LR	MM	PR	2.0	MA	1.0	30	30	14	14
G037.1	ST. PAUL	MN	17	1	1900	LR	MM	PR	1.9	MA	2.0				
G037.2	MINNEAPOLIS	MN	25	1	1920	LR	MM	PR	1.6	MA	2.0				
G037.3	ST. PAUL	MN	16	1	1938	LR	MM	PR	1.5	MA	2.0				
G037.4	ST. PAUL	MN	10	1	1890	LR	MM	PR	1.4	MA	2.0				
G037.5	ST. PAUL	MN	6	1	1920	LR	MM	PR	2.0	MA	2.0	5	44		

Table A-1. U.S. buildings data base: building characteristics (continued).

BLDG. LABEL	LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
G037.6	MINNEAPOLIS	MN	18	1	1929	LR	MM	PR	1.6	MA	2.0				
G037.7	ST. PAUL	MN	26	1	1916	LR	MM	PR	1.5	MA	2.0				
G038.1	MINNEAPOLIS	MN	33	1	1972	LR	MM	PR		FR	2.0				
G038.10	MINNEAPOLIS	MN	17	1	1965	LR	MM	PR		FR	2.0				
G038.12	FRIDLEY	MN	18	1	1962	LR	MM	PR		FR	2.0	5	5		
G038.13	MINNEAPOLIS	MN	11	1	1962	LR	MM	PR		FR	2.0	30	30		
G038.14	MINNEAPOLIS	MN	7	1	1962	LR	MM	PR		FR	2.0				
G038.15	MINNEAPOLIS	MN	30	1	1964	LR	MM	PR		FR	2.0				
G038.16	MINNEAPOLIS	MN	36	1	1964	LR	MM	PR		FR	2.0				
G038.17	MINNEAPOLIS	MN	20	1	1969	LR	MM	PR		FR	2.0				
G038.2	MINNEAPOLIS	MN	22	1	1971	LR	MM	PR		FR	2.0				
G038.3	MINNEAPOLIS	MN	12	1	1967	LR	MM	PR		FR	2.0				
G038.4	MINNEAPOLIS	MN	45	1	1971	LR	MM	PR		FR	2.0				
G038.5	MINNEAPOLIS	MN	27	1	1972	LR	MM	PR		FR	2.0				
G038.6	MINNEAPOLIS	MN	24	1	1972	LR	MM	PR		FR	2.0				
G038.7	MINNEAPOLIS	MN	20	1	1973	LR	MM	PR		FR	2.0				
G038.8	MINNEAPOLIS	MN	21	1	1971	LR	MM	PR		FR	2.0				
G038.9	MINNEAPOLIS	MN	23	1	1973	LR	MM	PR		FR	2.0				
G039	ASBURY PARK	NJ	60	2	1963	HR	MM	PU	1.3	CB	1.0	11	11	0	0
G039 *	ASBURY PARK	NJ	60	2	1963	HR	MM	PU	1.3	CB	1.0	11	11	0	0
G040.1	MINNEAPOLIS	MN	4	1	1964	LR	MM	PR		FR	2.0				
G040.10	ST. PAUL	MN	5	1	1966	LR	MM	PR		FR	2.0	19	19	10	10
G040.2	ST. PAUL	MN	16	1	1957	LR	MM	PR		FR	2.0			14	14
G040.3	MINNEAPOLIS	MN	4	1	1927	LR	MM	PR		FR	2.0				
G040.4	MINNEAPOLIS	MN	24	1	1971	LR	MM	PR		FR	2.0	18	40		
G040.5	ROCHESTER	MN	30	1	1975	LR	MM	PR		FR					
G040.6	ROCHESTER	MN	30	1	1978	LR	MM	PR		FR					
G040.7	ROCHESTER	MN	30	1	1978	LR	MM	PR		FR					
G040.8	ST. PAUL	MN	19	1	1966	LR	MM	PR		FR	2.0	19	19	10	10
G040.9	ST. PAUL	MN	5	1	1966	LR	MM	PR		FR	2.0	19	19	10	10
G041.1	CHICAGO	IL	6	1	1925	LR	MM	PR	3.3	MA					
G041.2	CHICAGO	IL	6	1	1925	LR	MM	PR	3.5	MA					
G041.3	CHICAGO	IL	12	1	1925	LR	MM	PR	4.0	MA					
G041.4	CHICAGO	IL	31	1	1925	LR	MM	PR	4.0	MA					
G041.5	CHICAGO	IL	27	1	1925	LR	MM	PR	2.7	MA					
G042.1	MINNEAPOLIS	MN	32	1	1920	LR	MM	PR		MA					
G042.2	MINNEAPOLIS	MN	7	1	1910	LR	MM	PR		MA					
G042.3	MINNEAPOLIS	MN	30	1	1968	LR	MM	PR		FR	2.0				
G042.4	MINNEAPOLIS	MN	17	1	1963	LR	MM	PR		FR	2.0				
G042.5	MINNEAPOLIS	MN	18	1	1962	LR	MM	PR		FR					

Table A-1. U.S. buildings data base: building characteristics (continued).

BLDG. LABEL	LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
G042.6	MINNEAPOLIS	MN	18	1	1974	LR	MM	PR		FR					
G043	ATLANTA	GA	16	1	1922	LR	MM	PR	2.0	BR	1.0	11	11	0	0
G044.1	PHILLIPSBURG	NJ	150	24	1951	LR	MM	PU		FR		0	30		
G044.2	PHILLIPSBURG	NJ	222	49	1942	LR	MM	PU		MA		0	30		
G045.1	MINNEAPOLIS	MN	11	1	1925	LR	MM	PR		FR	2.0				
G045.10	MINNEAPOLIS	MN	11	1	1930	LR	MM	PR		MA	2.0	38	38	0	0
G045.11	MINNEAPOLIS	MN	25	2	1915	LR	MM	PR		FR	2.0				
G045.12	MINNEAPOLIS	MN	26	1	1924	LR	MM	PR		MA	2.0				
G045.13	MINNEAPOLIS	MN	14	1	1922	LR	MM	PR		FR	2.0				
G045.2	MINNEAPOLIS	MN	32	1	1914	LR	MM	PR		FR	2.0			6	6
G045.3	MINNEAPOLIS	MN	17	1	1913	LR	MM	PR		FR	2.0	30	30		
G045.4	MINNEAPOLIS	MN	20	1	1924	LR	MM	PR		FR	2.0				
G045.5	MINNEAPOLIS	MN	45	1	1924	LR	MM	PR		FR	2.0	38	38	0	0
G045.6	MINNEAPOLIS	MN	6	1	1911	LR	MM	PR		FR	2.0	7	7		
G045.7	MINNEAPOLIS	MN	6	1	1911	LR	MM	PR		FR	2.0	7	7		
G045.8	MINNEAPOLIS	MN	40	1	1914	HR	MM	PR		BR	2.0				
G045.9	MINNEAPOLIS	MN	10	1	1930	LR	MM	PR		FR	2.0	38	38	0	0
G046	ASBURY PARK	NJ	126	12	1941	LR	MM	PU		BR		8	8	5	5
G047.1	ST. PAUL	MN	10	1	1940	LR	MM	PR	1.4	FR	2.0	8	48	0	9
G047.10	ST. PAUL	MN	17	1		LR	MM	PR				0	44	0	19
G047.11	ST. PAUL	MN	5	1	1930	LR	MM	PR		FR	2.0	0	44	0	19
G047.12	ST. PAUL	MN	165	14	1954	LR	MM	PR		MA		0	0	0	0
G047.2	ST. PAUL	MN	33	1	1910	LR	MM	PR	1.2	BR	2.0	10	10	0	0
G047.2 *	ST. PAUL	MN	33	1	1910	LR	MM	PR	1.2	BR	2.0	10	10	0	0
G047.3	ST. PAUL	MN	19	1	1940	LR	MM	PR	1.1	BR	2.0	8	48	0	0
G047.3 *	ST. PAUL	MN	19	1	1940	LR	MM	PR	1.1	BR	2.0	48	48	0	0
G047.4	ST. PAUL	MN	14	1	1920	LR	MM	PR	1.1	BR	2.0	5	48	0	0
G047.5	ST. PAUL	MN	52	2	1920	LR	MM	PR	1.5	BR	2.0	12	52	0	0
G047.5 *	ST. PAUL	MN	26	1	1920	LR	MM	PR	1.5	BR	2.0	52	52	0	0
G047.6	ST. PAUL	MN	6	1	1920	LR	MM	PR	1.5	BR	2.0	14	48	0	0
G047.7	ST. PAUL	MN	17	1	1930	LR	MM	PR	1.1	FR	2.0	33	33	0	11
G047.7 *	ST. PAUL	MN	17	1	1930	LR	MM	PR	1.1	FR	2.0	33	33	11	11
G047.8	ST. PAUL	MN	25	1	1964	LR	MM	PR	1.2	FR	2.0	9	9	10	10
G047.9	ST. PAUL	MN	24	2	1930	LR	MM	PR	1.4	MX	2.0	6	16	8	8
G048.1	CHICAGO	IL	11	1	1930	LR	MM	PR		MA	1.9	0		0	
G048.2	CHICAGO	IL	6	1	1903	LR	MM	PR		MA	1.0	11	11	0	0
G048.3	CHICAGO	IL	15	1	1904	LR	MM	PR		MA	2.0	0	0	0	0
G048.4	CHICAGO	IL	14	1	1916	LR	MM	PR		MA	1.0	0		0	0
G048.5	CHICAGO	IL	7	1	1924	LR	MM	PR		MA	1.5	0		0	0
G048.6	CHICAGO	IL	13	1	1925	LR	MM	PR		MA	1.6	0	0	0	0

Table A-1. U.S. buildings data base: building characteristics (continued).

BLDG. LABEL		LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
G048.7		CHICAGO	IL	12	1	1925	LR	MM	PR		MA	2.0	0	0	0	0
M015		ST. PAUL	MN	503	3	1964	HR	MM	PU		BR					
M016		TRENTON	NJ	112	14	1954	LR	MM	PU		MA	1.0				
M016	*	TRENTON	NJ	112	14	1954	LR	MM	PU		MA	1.0				
M017.1		NEW YORK	NY	91	1	1941	HR	MM	PR	3.0	MA	1.0				
M017.1	*	NEW YORK	NY	91	1	1941	HR	MM	PR	3.0	MA	1.0				
M017.1	**	NEW YORK	NY	91	1	1941	HR	MM	PR	3.0	MA	2.0				
M017.2		NEW YORK	NY	112	1	1939	HR	MM	PR		MA					
M017.2	*	NEW YORK	NY	112	1	1939	HR	MM	PR		MA					
M017.3		NEW YORK	NY	55	1	1937	HR	MM	PR		MA	2.0				
O002.1		TRENTON	NJ	159	3	1954	LR	MM	PU		MA	1.0				
O002.2B		TRENTON	NJ	1500	3	1954	LR	MM	PU							
O003		WASHINGTON	DC	521				MM	PR							
O004			MD	752				MM	PR							
O005		NEW YORK	NY	60	1			MM	PR							
O008.1		NEW YORK	NY	42	1	1952	HR	MM	PU		MA					
O008.1A		NEW YORK	NY	42	1	1952	HR	MM	PU		MA					
O008.2		NEW YORK	NY	98	1	1955	HR	MM	PU		MA					
O008.2A		NEW YORK	NY	98	1	1955	HR	MM	PU		MA	1.0				
O008.3		NEW YORK	NY	56	1	1958	HR	MM	PU		MA					
O008.3A		NEW YORK	NY	56	1	1958	HR	MM	PU		MA					
O008.4		NEW YORK	NY	81	1	1968	HR	MM	PU		MA					
O008.4A		NEW YORK	NY	81	1	1968	HR	MM	PU		MA					
O009.1		NEW YORK	NY	1444	15	1955	HR	MM	PU	3.0	MA	1.0				
O009.2		NEW YORK	NY	1338	27	1948	HR	MM	PU	3.2	MA	1.0				
O009.3		NEW YORK	NY	1791	15	1950	HR	MM	PU	3.0	MA	1.0				
O009.4		NEW YORK	NY	1310	10	1948	HR	MM	PU	2.8	MA	1.0				
O009.5		NEW YORK	NY	1229	9	1950	HR	MM	PU	3.0	MA	1.0				
O009.6		NEW YORK	NY	1084	13	1948	HR	MM	PU	2.8	MA	1.0				
O009.7		NEW YORK	NY	1246	13	1958	HR	MM	PU	2.7	MA	1.0				
O009.8		NEW YORK	NY	786	7	1951	HR	MM	PU	2.5	MA	1.0				
O009.9		NEW YORK	NY	733	6	1950	HR	MM	PU	2.5	MA	1.0				
O013		TRENTON	NJ	376	85	1939	LR	MM	PU		MA	1.0				
O014.1		TRENTON	NJ	102	5	1953	LR	MM	PU		MA	1.0				
O014.2		TRENTON	NJ	81	3	1953	LR	MM	PU		MA	1.0				
O014.3		TRENTON	NJ	219	8	1954	LR	MM	PU		MA	1.0				
O015		PHILADELPHIA	PA	886	30	1963	CO	MM	PU		MA					
O016.1		NEW YORK	NY	72	1	1935	HR	MM	PR		BR	1.0				

Table A-1. U.S. buildings data base: building characteristics (continued).

BLDG. LABEL	LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
0016.2	NEW YORK	NY	48	1	1938	HR	MM	PR		BR	1.0				
0016.3	NEW YORK	NY	110	1	1922	HR	MM	PR		BR	1.0				
0016.4	NEW YORK	NY	48	1	1936	HR	MM	PR		BR	1.0				
0016.5	NEW YORK	NY	24	1	1936	HR	MM	PR		BR	1.0				
0016.6	NEW YORK	NY	72	1	1929	HR	MM	PR		BR	1.0				
0016.7	NEW YORK	NY	49	1	1933	HR	MM	PR		BR	1.0				
0016.8	NEW YORK	NY	42	1	1930	HR	MM	PR		BR	1.0				
0017.1	PHILADELPHIA	PA	6	1	1925	LR	MM	PR		BR					
0017.2	PHILADELPHIA	PA	6	1	1925	LR	MM	PR		BR					
0018	NEW YORK CITY	NY	139	1	1968	HR	MM	PR		BR	1.0	9	9	9	9

Table A-2. U.S. buildings data base: energy consumption.

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI-DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
E012	L	865	1285.0	793.0	62	EST	67			S	C	4800	C	S	
E019.1	F	756	13061.6	963.5	7	SSHL	11	5898.3	987.4	R	B+	5185	I		E
E019.2	F	757	8151.6	1992.9	24	SSHL	19	5366.2	1652.0	R	B+	5185	I		E
E019.3	F	759	9122.0	1478.1	16	SSHL	12	5026.6	1402.9	R	B+	5185	I		E
E021	F	1060	10380.0	1475.0	14					S	C	4848	I		
E022	L		5674.0	638.0	11					S	C	4800			
E025	F	800	11543.1	1295.3	11			7608.6	-111.1	R	B+	4986	I		E
E026.1	A		3424.8	675.6	20					E	B	4800			
E026.2	A		5456.0	1050.8	19					E	B	4800			
E026.3	A		3206.4	559.2	17					E	B	4800			
E027.10	F	864	12616.4	2786.5	22	SSHL	36	4339.2	201.7	R	B+	4691	I		E
E027.11	F	833	14181.9	3641.9	26	SSHL	37	7544.8	2930.0	R	B+	4691	I		E
E027.13	F	739	8543.3	197.4	2	SSHL	30	4951.6	1458.8	R	B+	4691	I		E
E027.14	F	551	8478.6	2577.1	30	SSHL	47	4511.2	2050.3	R	B+	4691	I		E
E027.15	F	960	13020.9	2098.7	16	SSHL	42	9074.5	2188.1	R	B+	4691	I		E
E027.16	F	832	10361.0	1155.6	11	SSHL	32	5199.3	1385.1	R	B+	4691	I		E
E027.17	F	756	8100.9	1814.7	22	SSHL	38	5176.4	2198.4	R	B+	4691	I		E
E027.18	F	453	4623.1	1428.1	31	SSHL	115	3266.0	1810.3	R	B+	4691	I		E
E027.19	F	572	4458.4	381.3	9	SSHL	24	2988.3	1057.0	R	B+	4691	I		E
E027.20	F	967	17818.3	-395.8	- 2	SSHL	16	10889.7	2317.4	R	B+	4691	I		E
E027.21	F	768	13247.8	1907.7	14	SSHL	25	7513.8	1375.8	R	B+	4691	I		E
E027.22	F	985	13496.1	2604.5	19	SSHL	23	9596.7	4630.3	R	B+	4691	I		E
E027.23	F	903	8162.4	512.1	6	SSHL	33	4453.8	846.1	R	B+	4691	I		E
E027.24	F	714	8842.1	1711.4	19	SSHL	34	4356.3	1686.0	R	B+	4691	I		E
E027.3	F	796	10484.6	1960.7	19	SSHL	36	6891.2	4136.8	R	B+	4691	I		E
E027.4	F	816	11982.2	2757.4	23	SSHL	47	9056.4	4112.1	R	B+	4691	I		E
E027.5	F	720	11947.3	1575.4	13	SSHL	19	1807.5	651.6	R	B+	4691	I		E
E027.6	F	443	7890.0	-186.9	- 2	SSHL	31	4125.6	-1430.8	R	B+	4691	I		E
E027.7	F	1208	15884.0	505.0	3	SSHL	16	7033.5	-3447.9	R	B+	4691	I		E
E027.8	F	610	8411.8	2227.4	26	SSHL	42	6170.1	3203.1	R	B+	4691	I		E
E027.9	F	739	9243.8	2647.1	29	SSHL	56	5089.6	3050.1	R	B+	4691	I		E
E028.1	F	814	10309.0	-421.0	- 4			5487.9	151.0	F	A	5185	I		E
E028.10	F	688	9224.0	2128.0	23			6273.0	3343.5	F	A	5185	I		E
E028.11	F	1058	10982.0	1258.0	11			5828.5	1175.9	F	A	5185	I		E
E028.12	F	1280	15025.0	2548.0	17			7145.3	2163.2	F	A	5185	I		E
E028.13	F	917	12826.0	1796.0	14			9004.0	2463.3	F	A	5185	I		E
E028.14	F	590	8721.0	1646.0	19			4431.0	439.6	F	A	5185	I		E
E028.15	F	1050	12173.0	1551.0	13			8016.7	2137.9	F	A	5185	I		E
E028.2	F	440	6494.0	659.0	10			3813.4	1067.2	F	A	5185	I		E
E028.3	F	650	4663.0	306.0	7			4448.5	722.0	F	A	5185	I		G

Table A-2. U.S. buildings data base: energy consumption (continued).

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI-DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
E028.4	F	690	7810.0	16.0	0			3634.0	-176.0	F	A	5185	I		E
E028.5	F	783	11545.0	1109.0	10			5651.7	1529.3	F	A	5185	I		E
E028.6	F	732	8592.0	1212.0	14	HOUR	25	5551.0	1806.9	F	A	5185	I		E
E028.7	F	787	5686.0	731.0	13			4921.8	1063.3	F	A	5185	I		G
E028.8	F	728	10351.0	127.0	1			4531.3	-1051.7	F	A	5185	I		E
E028.9	F	690	7506.0	-496.0	- 7			3422.0	308.0	F	A	5185	I		E
E029.1	F	500	11760.0	1400.0	12					F	C	6014	I		E
E029.1A	F	500	12713.0	328.0	3					F	C	6014	I		E
G031.1	H	950	142.9	70.1	49			111.8	57.8	S	C	6500	B	S	G
G031.2	H	1030	178.7	71.0	40			139.7	57.5	S	C	6500	B	S	G
G031.3	H	1040	131.6	36.9	28			97.1	29.2	S	C	6500	B	S	G
G031.4	H	960	109.9	8.7	8			85.8	9.6	S	C	6500	B	S	G
G031.5	H	1200	262.7	131.5	50			227.4	119.7	S	C	6500	B	S	G
G031.6	H	1165	120.4	34.2	28			89.7	24.5	S	C	6500	B	S	G
G031.7	H	1280	136.0					108.8	39.7	S	C	6500	B	S	G
G031.8	H	765	97.0	32.3	33			84.9	26.0	S	C	6500	B	S	G
G032	H	738	162.4	16.3	10			116.8	16.3	S	C	4857	C	S	G
G035.1	F	869	93.2	9.2	10			15.5	-5.3	R	B+	3161	I		G
G035.11	W	554	58.8	1.1	2			16.1	0.8	R	B+	3161	C	W	G
G035.12	W	632	52.9	0.6	1			13.2	-7.2	R	B+	3161	C		G
G035.13	W	619	32.9	3.4	10			8.6	-0.8	R	B+	3161	C		G
G035.14	W	607	36.2	-0.6	- 2			1.2	-4.4	R	B+	3161	C		G
G035.15	W	587	59.5	7.6	13			7.3	0.5	R	B+	3161	C		G
G035.16	W	503	57.1	13.3	23			5.2	-5.5	R	B+	3161	C		G
G035.2	F	828	134.7	22.6	17			25.4	2.1	R	B+	3161	C	W	G
G035.4	F	836	164.1	33.5	20			11.2	-18.6	R	B+	3161	C	W	G
G035.5	F	870	86.6	4.0	5			21.1	-7.2	R	B+	3161	I		G
G035.6	F	771	79.4	-4.1	- 5			4.7	-9.5	R	B+	3161	C	W	G
G036.1	W	950	118.6	20.9	18			79.3	15.5	S	C	4872	G	W	G
G036.2	W	850	104.5	23.1	22			72.2	19.8	S	C	4872	G	W	G
G036.3	W	975	122.0	22.4	18			83.1	17.6	S	C	4872	G	W	G
G036.4	H	945						66.3	14.9	S	C	4872	G	W	G
G036.5	H	945						61.8	2.3	S	C	4872	G	W	G
G037.1	F	1529	208.2	56.9	27					F	B	8159	B	S	G
G037.2	F	582	85.9	17.1	20			72.5	20.0	R	B+	8159	B	S	G
G037.3	F	554	80.7	23.7	29			63.6	14.4	R	B+	8159	B	S	G
G037.4	F	680	93.8	16.5	18			81.3	16.2	R	B+	8159	B	S	G
G037.5	F	1800	202.4	49.6	25			179.1	49.2	R	B+	8159	B	S	G

Table A-2. U.S. buildings data base: energy consumption (continued).

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI- DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
G037.6	F	711	79.4	24.7	31			72.0	27.6	R	B+	8159	B	S	G
G037.7	F	446	71.0	9.3	13			58.1	7.7	R	B+	8159	B	S	G
G038.1	H	767						28.9	7.4	E	A	8159	B	W	G
G038.10	W	867	48.5	4.2	9			38.0	-3.0	R	B+	8159	B	W	G
G038.12	F	707	52.6	0.3	0			40.3	6.4	R	B+	8159	B	W	G
G038.13	W	835	45.7	4.1	9			42.9	7.4	R	B+	8159	B	W	G
G038.14	F	696	75.9	2.0	3					R	B	8159	B	W	G
G038.15	F	663	59.1	7.0	12			48.3	12.7	R	B+	8159	B	W	G
G038.16	F	667	54.8	8.3	15			38.8	9.5	R	B+	8159	B	W	G
G038.17	W	710	63.3	11.4	18					R	B	8159	B	W	G
G038.2	H	764						28.5	4.2	E	A	8159	B	W	G
G038.3	H	792						28.8	4.6	E	A	8159	B	W	G
G038.4	H	842						36.8	4.0	E	A	8159	B	W	G
G038.5	F	833	51.0	8.3	16			38.1	7.3	R	B+	8159	B	W	G
G038.6	F	771	47.1	3.3	7			38.5	3.2	R	B+	8159	B	W	G
G038.7	F	770	46.9	3.4	7			37.6	2.6	R	B+	8159	B	W	G
G038.8	F	757	49.1	7.8	16			40.3	10.3	R	B+	8159	B	W	G
G038.9	F	783	53.7	2.0	4			43.4	1.5	R	B+	8159	B	W	G
G039	F	653	107.8	-7.3	- 7			63.4	-31.8	R	B+	5034	C	S	G
G039 *	F	653	115.1	45.9	40			95.2	69.8	R	B+	5034	C	S	G
G040.1	F	700	89.9	19.4	22			66.0	10.8	R	B+	8159	B	W	
G040.10	F	1020	121.4	21.9	18			81.1	11.7	R	B+	8159	B	W	
G040.2	F	630	77.8	9.9	13			66.6	12.4	R	B+	8159	B	W	
G040.3	F	994	124.5	33.9	27			85.7	18.0	R	B+	8159	B	W	
G040.4	F	888	58.8	10.6	18			40.8	8.6	R	B+	8159	B	W	
G040.5	F	889	57.4	11.7	20			41.4	11.8	R	B+	8227	B	W	
G040.6	F	889	45.1	6.5	14			31.9	5.8	R	B+	8227	B	W	
G040.7	F	1026	47.5	6.4	13			33.2	8.0	R	B+	8227	B		
G040.8	F	993	98.9	9.0	9			79.7	10.6	R	B+	8159	B	W	
G040.9	F	1020	131.7	37.3	28			95.8	27.0	R	B+	8159	B	W	
G041.1	W	504	49.7	3.4	7					R	C	6497	B	W	G
G041.2	W	1560	241.3	3.5	1					R	C	6497	B	S	G
G041.3	W	1125	283.7	-10.6	- 4					R	C	6497	B	W	G
G041.4	W	1050	74.6	19.5	26					R	C	6497	B	W	G
G041.5	W	533	159.2	19.3	12					R	C	6497	B	W	G
G042.1	H	644						49.6	5.0	E	A	8159	B	S	G
G042.2	H	1909						139.7	11.5	E	A	8159	B	S	G
G042.3	H	607						32.1	3.3	E	A	8159	B	W	G
G042.4	H	679						36.9	2.3	E	A	8159	B	W	G
G042.5	H	907						31.9	-1.3	E	A	8159	B	W	G

Table A-2. U.S. buildings data base: energy consumption (continued).

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFIDENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
G042.6	H	852						33.7	5.7	E	A	8159	B	W	G
G043	W	1500	136.1	43.2	32			115.6	52.0	R	B+	3095	B	S	G
G044.1	F	1103	166.2	67.5	41			139.3	72.7	R	B+	4972	C		G
G044.2	F	1524	127.3	67.4	53			85.5	51.8	R	B+	4972	I		G
G045.1	F	859	94.0	5.5	6			86.6		F	B	8007	B	S	G
G045.10	F	1309	86.1	14.1	16	EST	18	82.2		F	B	8007	B	S	G
G045.11	F	801	122.1	15.1	12	EST	3			R	B+	8007	B	S	G
G045.12	F	1086	89.1	13.6	15	EST	11			R	B+	8007	B	S	G
G045.13	F	847	112.6	22.6	20	EST	9			R	B+	8007	B	S	G
G045.2	F	736	62.2	1.8	3			51.9		F	B	8007	B	S	G
G045.3	F	1477	74.0	-10.7	-15					F	B+	8007	B	S	G
G045.4	F	963	85.4	4.4	5	EST	6	74.1	4.9	R	B+	8007	B	S	G
G045.5	F	1116	79.4	11.0	14	EST	7	61.9	12.2	R	B+	8007	B	S	G
G045.6	F	1840	222.5	29.5	13	EST	9	203.8	37.4	R	B+	8007	B	S	G
G045.7	F	1840	202.2	26.8	13	EST	10	187.8	42.9	R	B+	8007	B	S	G
G045.8	F	630	87.0	2.7	3					F	B	8007	B	S	G
G045.9	F	1385	119.0	30.1	25	EST	15			F	B	8007	B	S	G
G046	F	708	211.0	110.6	52			153.0	94.3	R	B+	4972	C	S	G
G047.1	F	792	80.2	35.6	44	MONT	51	64.3	32.5	R	B+	8007	B	W	G
G047.10	D		9.7	3.0	31					E	B+	8007			G
G047.11	F	912	126.5	70.9	56	MONT	39	108.9	65.3	R	B+	8007	B	S	G
G047.12	H	741				MONT	24	84.3	27.7	R	B+	8007	B	W	G
G047.2	W	976	98.3	28.4	29	MONT	19	90.0	34.9	R	B+	8007	B	S	G
G047.2 *	W	976	73.5	4.8	7			53.6	0.3	R	B+	8007	B	W	G
G047.3	F	674	72.1	19.0	26	MONT	31			R	B+	8007	B	W	G
G047.3 *	H	674						37.8	5.7	R	B+	8007	B	W	G
G047.4	F	883	71.9	17.5	24	MONT	31	63.3	18.7	R	B+	8007	B	S	G
G047.5	F	737	77.5	16.6	21	MONT	22	67.2	10.5	R	B+	8007	B	S	G
G047.5 *	H	737						49.6	4.0	R	B+	8007	B	S	G
G047.6	F	1080	166.3	34.3	21	MONT	24	158.5	32.0	R	B+	8007	B	S	G
G047.7	F	669	62.2	35.0	56	MONT	58	50.9	32.7	R	B+	8007	B	S	G
G047.7 *	H	669						17.7	1.1	R	B+	8007	B	W	G
G047.8	F	765	49.1	3.8	8	MONT	16	39.5	6.5	R	B+	8007	B	W	G
G047.9	F	699	93.8	39.8	42	MONT	51	81.3	39.9	R	B+	8007	B	S	G
G048.1	W	728	144.4	32.4	22	SSHL	14	101.3	32.4	S	C	6455	B	S	G
G048.2	W	1760	203.7	52.7	26	SSHL	33	174.6	52.8	S	C	6455	B	S	G
G048.3	W	1200	245.6	96.2	39	SSHL	33	204.3	92.8	S	C	6455	B	S	G
G048.4	W	1095	122.0	8.0	7	SSHL	29	87.6	8.0	S	C	6455	B	S	G
G048.5	W	1186	153.4	39.9	26	SSHL	19	127.9	39.9	S	C	6455	B	S	G
G048.6	W	830	82.4	15.9	19	SSHL	18	72.6	15.9	S	C	6455	B	S	G

Table A-2. U.S. buildings data base: energy consumption (continued).

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI-DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
G048.7	W	1083	202.0	112.7	56	SSHL	28	192.3	112.7	S	C	6455	B	S	G
M015	W	410	64.8	11.6	18					S	C	8159	B	W	M
M016	F	862	184.4	-5.1	- 3			130.6	-6.1	R	B+	4952	C	W	O
M016 *	F	862	189.4	95.4	50			136.8	77.7	R	B+	4952	C	W	O
M017.1	W	659	126.6	48.4	38					S	C	4868	B	S	M
M017.1 *	W	659	78.2	1.2	2					S	C	4868	B	S	M
M017.1 **	W	659	77.0	14.0	18					S	C	4868	B	S	M
M017.2	W		111.8	27.0	24					S	C	4868	B	S	M
M017.2 *	W		84.8	1.6	2					S	C	4868	B	S	M
M017.3	W		113.6	18.5	16					S	C	4868	B		M
O002.1	W	830	113.8	50.6	44			83.0	50.4	S	C	4908	C	W	O
O002.2B	W		116.7	18.4	16			116.7	18.4	S	C	4911			O
O003	W		117.1	8.7	7					S	D	4211			O
O004	W		85.5	2.4	3					S	D	4211			O
O005	W		169.4	17.3	10					S	D	4848			O
O008.1	H	890						109.8	28.4	S	B	4800	C	S	O
O008.1A	H	890						110.3	17.0	S	B	4800	C	S	O
O008.2	H	850						38.8	9.6	S	B	4800	C	S	O
O008.2A	H	850						36.4	8.5	S	B	4800	C	S	O
O008.3	H	830						48.5	3.3	S	B	4800	C	S	O
O008.3A	H	830						45.5	-2.2	S	B	4800	C	S	O
O008.4	H	920						55.4	14.4	S	B	4800	C	S	O
O008.4A	H	920						54.6	16.0	S	B	4800	C	S	O
O009.1	H	850						67.2	12.0	S	C	4800	C	S	O
O009.2	H	775						63.8	9.7	S	C	4800	C	S	O
O009.3	H	810						73.1	16.2	S	C	4800	C	S	O
O009.4	H	810						67.2	11.2	S	C	4800	C	S	O
O009.5	H	840						74.8	10.8	S	C	4800	C	S	O
O009.6	H	760						68.8	14.2	S	C	4800	C	S	O
O009.7	H	825						60.1	10.2	S	C	4800	C	S	O
O009.8	H	845						62.7	11.2	S	C	4800	C	S	O
O009.9	H	850						62.4	5.9	S	C	4800	C	S	O
O013	F	779	152.5	26.2	17			118.8	34.5	R	B+	4952	C	S	O
O014.1	W	700	187.5	52.3	28			164.2	46.8	R	B+	4952	C		O
O014.2	W	790	198.6	27.9	14			167.1	27.8	R	B+	4952	C		O
O014.3	W	760	181.7	17.1	9			163.5	31.9	R	B+	4952	C		O
O015	F	1003	209.2	19.0	9			146.4	24.7	R	B+	4865	C	S	O
O016.1	W	1038	128.0	24.0	19					S	C	4848	B	S	O

Table A-2. U.S. buildings data base: energy consumption (continued).

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI-DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
O016.2	W	1038	114.0	21.0	18					S	C	4848	B	S	O
O016.3	W	1705	142.0	42.0	30					S	C	4848	B	S	O
O016.4	W	1015	124.0	17.0	14					S	C	4848	B	S	O
O016.5	W	975	138.0	31.0	22					S	C	4848	B	S	O
O016.6	W	1250	110.0	17.0	15					S	C	4848	B	S	O
O016.7	W	957	78.0	18.0	23					S	C	4848	B	S	O
O016.8	W	1126	144.0	22.0	15					S	C	4848	B	S	O
O017.1	H					EST	25	97.3	45.4	S	C	4865	B		G
O017.2	H					EST	23	65.0	15.2	S	C	4865	B		G
O018	W	1066	138.3	26.5	19			80.5	-12.9	R	B+	4848	B	S	O

Table A-3. U.S. buildings data base: retrofit characteristics.

BLDG. LABEL	RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
								(CENTS/KWH)			
E012	LS		79	108	-5	1.2	486	0.01	0.10	10	C
E019.1	IX,WH,WM	IHW,SET,IPI	81	685	0	15.7	-244	0.07	0.05	20	A
E019.2	IX,WH,WM,IA,CW,LS	SET,IPI	81	1381	0	15.3	-468	0.07	0.05	20	A
E019.3	IX,WH,WM	IHW,SET,IPI	81	1441	0	21.5	-764	0.09	0.05	20	A
E021	HC	EMR	80	503	18	3.9	769	0.04	0.10	20	C
E022	MC		80	99	2	2.0	411	0.02	0.08	20	B
E025	PI,CW,WH	SET,IHW	84	273	0	2.1	625	0.03	0.10	10	B
E026.1	MC		83	478	21	7.1	105	0.11	0.13	15	C
E026.2	MC		83	223	21	1.9	794	0.04	0.13	15	C
E026.3	MC		83	478	21	9.2	-33	0.13	0.13	15	C
E027.10	IA,IF,WM,CW		85	3449	0	22.9	-2043	0.13	0.05	17	B
E027.11	WM,DS,CW,IA,IF,WH	IHW,IPI,LFS	85	2976	0	15.1	-1256	0.09	0.05	15	B
E027.13	WM,DS,CW,WH,IA,IF	IHW,LFS,IPI	85	1815	0	170.2	-1722	1.01	0.05	15	B
E027.14	WM,DS,CW,IA,IF,WH	IHW,IPI,LFS	85	2150	0	15.4	-932	0.09	0.05	15	B
E027.15	IA,IF,WM,DS,CW,WH	LFS,IHW,IPI	85	3121	0	27.5	-2129	0.16	0.05	15	B
E027.16	WM,DS,CW,WH,IA,IF	IPI,IHW,LFS	85	2230	0	35.7	-1685	0.21	0.05	15	B
E027.17	WM,CW,WH,IA,IF	LFS	85	1723	0	17.6	-807	0.10	0.05	17	B
E027.18	IW,IA,IF,WM,CW,HX		85	3083	0	40.0	-2362	0.22	0.05	17	B
E027.19	WM,WH	LFS	85	351	0	17.0	-171	0.10	0.05	15	B
E027.20	WM,CW,HX,WH,DS,IF	IHW,LFS,IPI	85	2478	0		-2651		0.05	13	B
E027.21	WM,CW,WH,IA,IF,IW	LFS,IHW,IPI	85	1810	0	17.6	-848	0.10	0.05	17	B
E027.22	IA,IF,WM,CW,HX,DS,WH	LFS	85	2966	0	21.1	-1735	0.13	0.05	15	B
E027.23	WM,DS,CW,WH,IA,IF	LFS,IHW,IPI	85	1514	0	54.7	-1272	0.32	0.05	15	B
E027.24	WM,CW,WH,IA,IF	LFS,IPI,IHW	85	1592	0	17.2	-728	0.10	0.05	17	B
E027.3	IA,IF,WM,CW,DS,WH	IPI,IHW,LFS	85	2287	0	21.6	-1361	0.13	0.05	15	B
E027.4	IA,IF,WM,CW,WH	IPI,LFS	85	3350	0	22.5	-1958	0.12	0.05	17	B
E027.5	IF,CW,WH	IHW,LFS,IPI	85	1363	0	16.0	-505	0.08	0.05	20	B
E027.6	WM,CW,WH,IF	IPI,IHW	85	1153	0		-1248		0.05	17	B
E027.7	WM,CW,HX,IA,WH	IHW,IPI,LFS	85	2604	0	95.5	-2366	0.57	0.05	15	B
E027.8	IF,IW,WM,CW		85	2711	0	22.5	-1588	0.12	0.05	17	B
E027.9	WM,CW,IA,IF,IW,WH	LFS	85	3087	0	21.6	-1751	0.12	0.05	17	B
E028.1	WM,WH	LFS	86	761	0		-943		0.04	20	A
E028.10	IA,SR,WM,IF,WH	LFS	86	1755	0	19.2	-831	0.08	0.04	20	A
E028.11	WR,WH	LFS	86	1278	0	23.6	-732	0.10	0.04	20	A
E028.12	WM,WH	LFS	86	1373	0	12.5	-267	0.05	0.04	20	A
E028.13	IA,WR,WH	LFS	86	1786	0	23.1	-1007	0.09	0.04	20	A
E028.14	IA,SR,WM,IF,WH	LFS	86	3760	0	53.1	-3045	0.22	0.04	20	A
E028.15	WM,WH	LFS	86	1163	0	17.4	-490	0.07	0.04	20	A
E028.2	WR,IF,WH	LFS	86	740	0	26.1	-454	0.11	0.04	20	A
E028.3	IA,IF,IW,WM		86	1563	0	118.7	-1430	0.48	0.04	20	A

Table A-3. U.S. buildings data base: retrofit characteristics (continued).

BLDG. LABEL	RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
E028.4	WM,IF,DR,WH	LFS	86	1348	0	1958.3	-1341	7.95	0.04	20	A
E028.5	WM,WH	LFS	86	848	0	17.8	-367	0.07	0.04	20	A
E028.6	IA,IF,IW,WR		86	5108	0	99.1	-4588	0.40	0.04	20	A
E028.7	IA,WR,IF		86	1660	0	52.8	-1343	0.21	0.04	20	A
E028.8	WM,IF,WH	LFS	86	817	0	149.6	-762	0.61	0.04	20	A
E028.9	WM,IF,WH	LFS	86	788	0		-1003		0.04	20	A
E029.1	CW		86	61	0	0.7	281	0.01	0.06	5	C
E029.1A											C
								($ /	MBTU)		
G031.1	IA,HC,HS,OM	TU,FD,TRV,CUT,OMP	81	736	35	2.7	3591	2.00	6.85	15	A
G031.2	IA,HS,OM	TU,FD,TRV,CUT,OMP	81	686	35	2.5	3616	1.92	6.85	15	A
G031.3	IA,HC,HS,WM,OM	TU,FD,TRV,CUT,OMP	81	1395	35	11.4	591	6.44	6.85	15	A
G031.4	HC,HS,OM,ID	TU,FD,TRV,VDE,OMP	81	303	35	18.0	78	7.11	6.85	15	A
G031.5	IA,WM,HS,OM	TU,FD,CUT,OMP,VDT	81	994	35	1.6	8398	1.20	6.85	15	A
G031.6	HS,OM	TU,FD,TRV,CUT,OMP,VDT	81	341	35	3.5	1260	2.96	6.85	15	A
G031.7	HS,OM	TU,TUR,FD,RHB,TRV,CUT	81	1243	35	6.9	1602	4.32	6.85	15	A
G031.8	HS,HC,OM	TU,RHB,TRV,CUT,OMP	81	341	35	3.2	1382	2.79	6.85	15	A
G032	CM,OM,HR	SHW,EMC	82	301	40	4.8	308	5.08	6.72	10	B
G035.1	IA,WH,CW	IHW	82	229	0	4.3	230	3.55	5.85	10	B
G035.11	SW		84	567	2	184.2	-537	75.20	4.77	10	B
G035.12	SW		84	562	2	810.9	-553	136.84	4.77	10	B
G035.13	SW		84	592	2	42.1	-469	25.37	4.77	10	B
G035.14	SW		84	656	2		-696		4.81	10	B
G035.15	SW		84	578	2	17.0	-284	11.09	4.77	10	B
G035.16	SW		84	607	2	9.8	-77	6.66	4.81	10	B
G035.2	IA,WH,CW,HC	LFS,CLT	82	105	0	0.8	1022	0.66	5.85	10	B
G035.4	IA,CW,HC	CLT	82	187	0	1.0	1485	0.79	5.85	10	B
G035.5	IA,WH,CW	IHW	82	181	0	7.7	19	6.44	5.85	10	B
G035.6	IA,CW,HC	CLT	83	93	0		-295		5.77	10	B
G036.1	WH	SHT,SET	82	148	0	1.2	1694	0.67	5.92	20	C
G036.2	WH	SHT,SET	82	148	0	1.1	1888	0.60	5.92	20	C
G036.3	WH	SHT,SET	82	148	0	1.1	1826	0.62	5.92	20	C
G036.4	HC	RES,BTC	82	36	3	0.4	669	0.54	5.73	10	C
G036.5	HC	RES,BTC	82	36	3	3.6	53	3.50	5.73	10	C
G037.1	HR,HC,WH	SHW,RES,CUT,HWR	83	4262	-20	10.9	2444	6.08	6.49	25	B
G037.2	HR,HC	SHW,RES	82	788	-20	5.8	1463	2.78	6.64	25	B
G037.3	HR,WH,HC	SHW,RES,CUT,SHT	81	598	-20	3.2	2516	1.32	6.85	25	B
G037.4	HR,HC	SHW,TRV,RES	81	1065	-20	7.3	1323	4.33	7.27	25	B
G037.5	HR,HC,IA	SHW,RES,HRE	83	4153	-20	12.4	1583	6.78	6.33	25	B

Table A-3. U.S. buildings data base: retrofit characteristics (continued).

BLDG. LABEL	RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
G037.6	HR,HC	SHW,RES,CUT	83	403	-20	2.2	2614	0.59	6.40	25	B
G037.7	HR,HC	SHW,RES	81	1919	-20	21.0	-468	15.56	7.15	25	B
G038.1	HC	RES,CUT	82	15	0	0.3	404	0.29	6.64	10	B
G038.10	HC	RES,CUT	84	38	0	1.5	182	1.27	6.12	10	B
G038.12	HC	RES,CUT	84	38	0	20.5	-22	17.82	6.12	10	B
G038.13	HC	RES,CUT	84	59	0	2.4	155	2.05	6.12	10	B
G038.14	HC	RES,CUT	84	91	0	7.5	13	6.49	6.12	10	B
G038.15	HC	RES,CUT	84	23	0	0.5	343	0.46	6.12	10	B
G038.16	HC	RES,CUT	84	19	0	0.4	414	0.33	6.12	10	B
G038.17	HC	RES,CUT	84	34	0	0.5	561	0.43	6.12	10	B
G038.2	HC	RES,CUT	82	23	0	0.8	215	0.79	6.64	10	B
G038.3	HC	RES,CUT	82	43	0	1.4	218	1.33	6.64	10	B
G038.4	HC	RES	83	74	0	2.9	145	2.62	6.40	10	B
G038.5	HC	RES	83	12	0	0.2	442	0.19	6.40	10	B
G038.6	HC	RES	83	12	0	0.5	169	0.48	6.40	10	B
G038.7	HC	RES	83	14	0	0.7	171	0.61	6.40	10	B
G038.8	HC	RES	83	13	0	0.3	413	0.24	6.40	10	B
G038.9	HC	RES	83	12	0	1.0	97	0.87	6.40	10	B
G039	HC,WH	RES, SHT	82	396	0		-974		6.63	15	B
G039 *	WM,HS	OMP,OMC	84	574	0	2.0	713	3.05	6.12	5	B
G040.1	MC		82	143	18	1.3	800	1.98	6.57	10	B
G040.10	MC		82	107	18	0.9	988	1.51	6.64	10	B
G040.2	MC		82	92	18	2.1	319	3.14	6.57	10	B
G040.3	MC		82	106	18	0.5	1707	0.98	6.78	10	B
G040.4	MC,IA		83	110	18	2.3	331	3.18	6.45	10	B
G040.5	MC		82	105	18	1.9	411	2.82	6.64	10	B
G040.6	MC		82	88	18	3.9	134	4.70	6.64	10	B
G040.7	MC		82	88	18	4.1	128	4.77	6.64	10	B
G040.8	MC		82	107	18	2.7	257	3.69	6.64	10	B
G040.9	MC		82	107	18	0.5	1861	0.89	6.64	10	B
G041.1	CW,WM		81	896	0	40.5	-632	28.94	6.50	15	C
G041.2	CW,IA,WM,DR		81	560	0	24.6	-288	17.58	6.50	15	C
G041.3	WM,DR,CW		82	1007	0		-1559		6.10	10	C
G041.4	WM,DR,CW		82	984	0	8.3	31	7.18	6.10	10	C
G041.5	WM,DR,CW		82	641	0	5.4	363	4.73	6.10	10	C
G042.1	HS	VDE	84	56	3	2.1	277	1.84	6.08	15	A
G042.2	HS	VDE	84	129	6	2.0	648	1.75	6.08	15	A
G042.3	HS,WH	VDE	84	97	5	6.6	94	4.74	6.08	15	A
G042.4	HS,WH	VDE	84	138	7	38.8	-75	9.66	4.80	15	A
G042.5	HS,WH	VDE	85	88	4		-199		5.87	15	A

Table A-3. U.S. buildings data base: retrofit characteristics (continued).

BLDG. LABEL		RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
G042.6		HS,WH	VDE	85	148	7	5.6	110	4.09	5.87	15	A
G043		CM	EMC	82	143	50	1.0	1229	1.63	4.81	10	C
G044.1		WM,IA,DR,IW,IF,HC,SR	OMC	83	14483	0	29.2	- 5817	18.41	7.36	25	B
G044.2		WM,DR,IA,HR,HC,IW,SR		82	13430	0	25.9	- 4387	17.10	7.69	25	B
G045.1		HS,HC	TRV,MSB	84	149	0	4.5	132	3.86	5.99	10	A
G045.10		HS,HC	TRV,MSB	84	122	0	1.4	599	1.24	5.99	10	A
G045.11		HS,HC	TRV,MSB	84	30	0	0.3	743	0.28	5.99	10	A
G045.12		HS,HC	TRV,MSB	84	76	0	0.9	620	0.80	5.99	10	A
G045.13		HS,HC	TRV,MSB	84	82	0	0.6	1075	0.51	5.99	10	A
G045.2		HS,HC	TRV,MSB	84	38	0	3.5	55	2.97	5.99	10	A
G045.3		HS,HC	TRV,TU,MSB	84	129	0		- 676		5.99	10	A
G045.4		HS,HC	TRV,MSB	84	30	0	1.1	195	0.97	5.99	10	A
G045.5		HS,HC	TRV,MSB	84	42	0	0.6	521	0.54	5.99	10	A
G045.6		HS,HC	TRV,TU,MSB	84	267	0	1.5	1242	1.29	5.99	10	A
G045.7		HS,HC	TRV,TU,MSB	84	254	0	1.6	1117	1.35	5.99	10	A
G045.8		HS,HC	TRV,MSB	84	28	0	1.7	110	1.47	5.99	10	A
G045.9		HS,HC	TRV,MSB	84	103	0	0.6	1437	0.49	5.99	10	A
G046		HR,WH,HC	HRM,SHT	83	3515	- 100	4.4	7844	2.09	6.18	20	B
G047.1		HC,HR,IA,IW,DR,CW,WH	CLT,HRE	85	1121	0	5.6	1886	2.97	5.67	20	A
G047.10		WH	HWR	85	217	0	12.7	80	6.20	5.67	25	A
G047.11		HS,HC,IA,IW,CW,WH	SHW,CLT,VDT	85	2278	0	5.7	3713	3.03	5.67	20	A
G047.12		HS,HC,CW	FEB,RES,CUT	85	674	0	4.3	1667	2.29	5.67	20	A
G047.2		HC,HS,WM,CW,WH	SHW,FEB,CLT	85	712	0	4.4	1687	2.37	5.67	20	A
G047.2	*	HS,WH	FEB	85	176	0	6.5	299	3.14	5.67	25	A
G047.3		HC,HS,IA,CW,WH	VDE,FEB,CLT	85	625	0	5.8	980	3.10	5.67	20	A
G047.3	*	HS,WH	FEB	85	332	0	10.3	231	5.00	5.67	25	A
G047.4		HC,IA,WM,CW,WH,HS	CLT,MSB	85	412	0	4.1	775	2.58	5.67	15	A
G047.5		HS,HC,IA,CW,WR,WH	CLT,VDE,MSB	85	744	0	7.9	381	4.92	5.67	15	A
G047.5	*	HS	VDE	85	18	0	0.8	253	0.49	5.67	15	A
G047.6		HS,HC,IA,WM,CW,WH	CLT,MSB	85	1073	0	5.5	1252	3.43	5.67	15	A
G047.7		HR,HC,IW,CW,WH	SHW,FEB,RES,CUT,HRE	85	1032	0	5.2	1925	2.78	5.67	20	A
G047.7	*	HC	CUT	85	7	0	1.2	46	0.95	5.67	10	A
G047.8		CW,HC,HS,WH	RES,CUT,VDE,FEB	85	274	0	12.7	46	6.82	5.67	20	A
G047.9		HC,HR,IA,CW,WH	RES,CUT,FEB,SHW	85	1557	0	6.9	1806	3.69	5.67	20	A
G048.1		IA,HS,OM,HC,WH	VDT,CUT,OMP	85	411	0	2.0	1992	1.39	6.21	15	B
G048.2		WM,HS,HC,WH,CW,OM	OMP,CUT,TU,LFS,VDT	84	2511	0	7.6	1017	5.70	6.29	13	B
G048.3		IA,HR,HC,WH	HRE,CUT	85	1269	0	2.1	7568	1.25	6.16	20	B
G048.4		IA,CW,HS,HW,LS,SR,OM,HC	TU,OMP,VDT	85	1095	0	22.3	- 541	15.65	6.13	14	B
G048.5		IA,WM,HS,CW,HC	VDT,OMP	85	1351	0	5.5	1573	3.72	6.13	15	B
G048.6		HS,HC,WH,OM	OMP,CUT	85	746	0	7.7	419	5.15	6.13	15	B

Table A-3. U.S. buildings data base: retrofit characteristics (continued).

BLDG. LABEL		RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
G048.7		HS,HC,HR,IA,OM	HRE	85	1167	0	1.7	9127	0.98	6.13	20	B
M015		CM,LC	EMR	81	368	0	4.5	323	4.51	6.98	10	C
M016		WR		83		0					15	B
M016	*	HR	HRM	84	575	-10	1.1	8146	0.41	7.19	25	F
M017.1		HR		80	440	0	1.2	5232	0.86	7.87	20	B
M017.1	*	WH,ID,WR	SHT	82	1490	0	171.3	-1360	117.14	7.25	20	B
M017.1	**	IA,CM	EMC	84	264	0	2.7	893	2.07	6.91	15	B
M017.2		HR,WH	SHT	81	609	0	2.8	2678	2.13	8.17	20	B
M017.2	*	CM,WR	EMC	83	1055	0	88.3	-876	62.20	7.46	20	B
M017.3		HR		83	603	0	4.8	1279	3.08	6.83	20	B
O002.1		HC,HS,WH		81	520	25	1.0	3787	1.96	10.49	10	B
O002.2B						0						B
O003		HS,HC,OM		78	27	20	3.0	99	2.74	4.69	10	D
O004		HS,HC,OM		78	16	13		-64	6.36	4.69	10	D
O005		HS,HC,OM		78	63	100		-484	6.30	4.69	10	D
O008.1		HC	TRV	77	248	10	2.3	703	1.60	4.43	10	B
O008.1A						0						B
O008.2		HC	TRV	77	210	10	8.4	30	4.15	4.43	10	B
O008.2A						0						B
O008.3		HC	TRV	77	164	10		-163	10.10	4.43	10	B
O008.3A						0						B
O008.4		HC	TRV	77	225	10	4.9	196	2.92	4.43	10	B
O008.4A						0						B
O009.1		WR		80	1339	-30	9.9	508	8.03	8.08	20	C
O009.2		WR		80	1639	-30	14.4	-107	12.86	7.88	20	C
O009.3		WR		80	1596	-30	9.2	812	7.45	8.27	20	C
O009.4		WR		80	1765	-30	13.4	27	12.20	8.27	20	C
O009.5		WR		81	1557	-30	13.9	-31	10.84	7.24	20	C
O009.6		WR		80	1408	-30	9.2	704	7.24	8.08	20	C
O009.7		WR		80	1281	-30	10.6	350	8.91	8.08	20	C
O009.8		WR		81	1233	-30	10.3	404	7.72	7.55	20	C
O009.9		WR		81	1245	-30	16.2	-247	14.83	7.24	20	C
O013		HC	RES	81	482	40	2.7	2396	3.27	8.76	20	B
O014.1		HR,HC	RES	80	2145	60	7.1	2708	5.02	7.29	20	B
O014.2		HR,HC	RES	80	4017	45	29.4	-1716	15.20	7.10	20	B
O014.3		HR,HC	RES	82	1637	60	28.7	-492	12.54	7.35	20	B
O015		HC	RES	81		0					20	F
O016.1		HR,CM	OMP,EMC	80	1024	4	5.4	1263	4.85	8.15	15	C

Table A-3. U.S. buildings data base: retrofit characteristics (continued).

BLDG. LABEL	RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
0016.2	HR,WR,CM	OMP,EMC	80	2943	4	17.8	- 948	15.58	8.15	15	C
0016.3	HR,WR,CM	OMP,EMC	80	2568	4	7.6	1472	6.81	8.15	15	C
0016.4	HR,WR,CM	OMP,EMC	82	2522	4	23.0	- 1198	16.53	6.73	15	C
0016.5	HR,WR	OMP	83	3269	4	15.0	- 643	11.71	7.20	15	C
0016.6	HR,WR,CM	OMP,EMC	81	2508	4	21.2	- 1077	16.44	7.27	15	C
0016.7	HR,WR,CM	OMP,EMC	83	2376	4	19.0	- 868	14.72	7.20	15	C
0016.8	HR,WR,CM	OMP,EMC	82	2101	4	14.8	- 397	10.67	6.65	15	C
0017.1	HC,WH,IA,WM	CLT,RES	84	2136	0	5.2	2811	5.17	9.12	15	B
0017.2	HC,WH,HS	CLT,RHB,OMB,RES,TU,VD	84	1918	0	13.8	- 262	13.86	9.12	15	B
0018	HC,OM,HS	RHB,CUT,OMC,OMP,TUR	84	351	14	2.4	930	2.42	6.13	10	B

Table A-4. European buildings data base: building characteristics.

BLDG. LABEL	LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
G049.1		SWZ	176	15	1950	LR		PR							
G049.2		SWZ	3	1	1932	LR		PR							
G049.3		SWZ	1072	85	1972			PR							
G050		FRN	260	4	1961	LR	MM	PR							
M014.1		SWD	453	30	1940			PR						8	14
M014.2		SWD	1429	25	1960			PR				13	27		
M014.7		SWD	3470	63	1953			PR							
M018.1	MOULINS	FRN	300	7	1961	CO	MM	PR							
M018.2	NANTES	FRN	304	20		LR	MM	PR							
M018.3	NANCY	FRN	2912	15	1960	CO	MM	PR							
M018.4		FRN	734	12		CO	MM	PR							
M019	VOIRON	FRN	40	1		HR	MM								
O019.1		SWZ	48	1	1973	HR		PR							
O019.10		SWZ	6	1	1955	LR		PR							
O019.11		SWZ	9	1		LR		PR							
O019.12		SWZ	11	1	1944	LR		PR							
O019.13		SWZ	540	41	1945	LR		PR							
O019.14		SWZ	60	4	1970	HR		PR							
O019.16		SWZ	6	1	1970			PR							
O019.17		SWZ	6	1	1969	LR		PR							
O019.18		SWZ	164	3	1965	HR		PR							
O019.19		SWZ	84	4	1962	LR		PR							
O019.2		SWZ	33	1	1964	LR		PR							
O019.20		SWZ	18	2	1972	LR		PR							
O019.21		SWZ	12	1	1964	LR		PR							
O019.22		SWZ	3	1	1902	LR		PR							
O019.23		SWZ	21	1	1930	HR		PR							
O019.24		SWZ	16	1	1970	LR		PR							
O019.26		SWZ	15	1	1953	LR		PR							
O019.27		SWZ	24	1	1960	LR		PR							
O019.28		SWZ	28	1	1959	LR		PR							
O019.29		SWZ	6	1	1952	LR		PR							
O019.3		SWZ	3	1	1952	LR		PR							
O019.30		SWZ	6	1	1967	LR		PR							
O019.31		SWZ	97	13	1960	LR		PR							
O019.32		SWZ	36	2	1962	LR		PR							
O019.33		SWZ	14	1	1962	LR		PR							
O019.34		SWZ	16	2	1959	LR		PR							
O019.35		SWZ	4	1	1953	LR		PR							

Table A-4. European buildings data base: building characteristics (continued).

BLDG. LABEL	LOCATION	NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
0019.36	SWZ	27	1	1959	HR		PR							
0019.37	SWZ	3	1	1930	LR		PR							
0019.38	SWZ	24	1		LR		PR							
0019.39	SWZ	350	3	1960	HR		PR							
0019.4	SWZ	16	1	1907	HR		PR							
0019.40	SWZ	24	1	1962	HR		PR							
0019.41	SWZ	44	1	1967	HR		PR							
0019.42	SWZ	8	1	1967	LR		PR							
0019.43	SWZ	6	1	1965	LR		PR							
0019.44	SWZ	27	1	1964	LR		PR							
0019.45	SWZ	8	1	1915	HR		PR							
0019.46	SWZ	33	4	1960	LR		PR							
0019.47	SWZ	40	2	1968	HR		PR							
0019.48	SWZ	6	1	1973	LR		PR							
0019.49	SWZ	18	3	1960	LR		PR							
0019.5	SWZ	11	1	1962	HR		PR							
0019.50	SWZ	56	4	1960	LR		PR							
0019.51	SWZ	96	3	1970	HR		PR							
0019.52	SWZ	10	1	1968	LR		PR							
0019.53	SWZ	16	2	1959	LR		PR							
0019.54	SWZ	5	1	1954	LR		PR							
0019.55	SWZ	24	1	1961	LR		PR							
0019.56	SWZ	14	1	1961	LR		PR							
0019.57	SWZ	14	1	1961	LR		PR							
0019.58	SWZ	14	1	1961	LR		PR							
0019.59	SWZ	34	3	1962	LR		PR							
0019.6	SWZ	4	1	1910	LR		PR							
0019.60	SWZ	96	2	1968	HR		PR							
0019.61	SWZ	58	1	1965	HR		PR							
0019.62	SWZ	6	1	1960	LR		PR							
0019.63	SWZ	84	5	1925	HR		PR							
0019.64	SWZ	54	2	1967	HR		PR							
0019.65	SWZ	19	2	1969			PR							
0019.66	SWZ	8	1	1911	LR		PR							
0019.67	SWZ	6	1	1960	LR		PR							
0019.68	SWZ	122	6	1925	LR		PR							
0019.69	SWZ	30	1	1964	LR		PR							
0019.7	SWZ	3	1	1913	LR		PR							
0019.70	SWZ	15	2	1963	LR		PR							
0019.9	SWZ	22	1	1960	LR		PR							
0020.1	SWZ	23	1	1965	LR		PR							

Table A-4. European buildings data base: building characteristics (continued).

BLDG. LABEL	LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
0020.10		SWZ	49	1	1953	HR		PR							
0020.11		SWZ	24	1	1960	LR		PR							
0020.12		SWZ	105	3	1970	HR		PR							
0020.13		SWZ	16	1	1964	LR		PR							
0020.14		SWZ	4	1	1952	LR		PR							
0020.15		SWZ	3	1	1900			PR							
0020.16		SWZ	4	1	1943	LR		PR							
0020.17		SWZ	4	1				PR							
0020.18		SWZ	3	1				PR							
0020.19		SWZ	4	1				PR							
0020.2		SWZ	28	1	1973	LR		PR							
0020.20		SWZ	4	1				PR							
0020.21		SWZ	3	1				PR							
0020.22		SWZ	3	1				PR							
0020.23		SWZ	3	1				PR							
0020.24		SWZ	4	1				PR							
0020.25		SWZ	4	1				PR							
0020.26		SWZ	4	1				PR							
0020.27		SWZ	4	1				PR							
0020.28		SWZ	4	1				PR							
0020.29		SWZ	4	1				PR							
0020.30		SWZ	4	1				PR							
0020.31		SWZ	4	1				PR							
0020.32		SWZ	3	1				PR							
0020.33		SWZ	20	1	1970	LR		PR							
0020.34		SWZ	20	1	1970	LR		PR							
0020.35		SWZ	4	1	1954	LR		PR							
0020.4		SWZ	16	1	1957	LR		PR							
0020.5		SWZ	37	1	1977	HR		PR							
0020.6		SWZ	24	1	1974	HR		PR							
0020.7		SWZ	24	1	1957	LR		PR							
0020.8		SWZ	7	1	1938	LR		PR							
0020.9		SWZ	114	3	1973	HR		PR							
0021	MARSEILLE	FRN	1489	15		HR	MM								
0022.1	NIORT	FRN	24	1		HR									
0022.2	NIORT	FRN	32	1		LR									
0022.3	NIORT	FRN	12	1		LR					1.0				
0022.4	NIORT	FRN	12	1		LR									
0023.1	VOIRON	FRN	21	1		HR	MM								
0023.2	VOIRON	FRN	23	1		HR	CM				1.0				
0023.3	VOIRON	FRN	21	1		HR	CM				1.0				

Table A-4. European buildings data base: building characteristics (continued).

BLDG. LABEL	LOCATION		NO. OF APT. UNITS	NO. OF BLDGS	YEAR BUILT	BLDG. TYPE	METER TYPE	OWNER-SHIP	NO. OF OCCUP. PRE	WALL TYPE	NO. OF GLAZING LAYERS	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL
O023.4	VOIRON	FRN	21	1		HR	CM				1.0				
O024.1	GRENOBLE	FRN	24	1		LR	MM				2.0				
O024.2	GRENOBLE	FRN	45	1		HR	MM				1.0				
X001.1		SWD	36	1		HR	MM	PR	1.8	CB	2.0	3		6	
X001.1 *		SWD	36	1		HR	MM	PR	1.8	CB	2.0	3			
X001.2		SWD	34	1		HR	MM	PR	1.8	CB	2.0	14		6	
X001.2 *		SWD	34	1		HR	MM	PR	1.8	CB	2.0			6	
X001.2 **		SWD	34	1		HR	MM	PR	1.8	CB	2.0			6	
X001.3		SWD	36	1		HR	MM	PR	1.8	CB	2.0	5		6	
X001.4		SWD	38	1		HR	MM	PR	1.8	CB	2.0	6		6	
X001.4 *		SWD	38	1		HR	MM	PR	1.8	CB	2.0	6		6	
X001.5		SWD	38	1		HR	MM	PR	1.8	CB	2.0	8		6	
X001.6		SWD	38	1		HR	MM	PR	1.8	CB	2.0	10		6	
X001.6 *		SWD	38	1		HR	MM	PR	1.8	CB	2.0			6	
X001.7		SWD	38	1		HR	MM	PR	1.8	CB	2.0	14		6	
X001.8		SWD	38	1		HR	MM	PR	1.8	CB	2.0	6		6	
X001.9		SWD	36	1		HR	MM	PR	1.8	CB	2.0	8		6	
X001.9 *		SWD	36	1		HR	MM	PR	1.8	CB	2.0	8			
X002.1	UMEA	SWD	476	31	1970	LR	MM	PR		CB	2.0	19	19	19	19
X002.2	UMEA	SWD	22	2	1970	LR	MM	PR		CB	2.0	19	19	19	19
X002.3	UMEA	SWD	12	1	1970	LR	MM	PR		CB	2.0	19	19	19	19
X002.4	UMEA	SWD	12	1	1970	LR	MM	PR		CB	2.0	19	19	19	19
X002.5	UMEA	SWD	39	1	1970	LR	MM	PR		CB	2.0	19	19	19	19

Table A-5. European buildings data base: energy consumption.

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI- DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
G049.1	W	893	75.9	12.6	17						D	5800			
G049.2	W	861	109.1	12.5	11						D	5800			
G049.3	W	1053	125.3	48.2	0						D	5400			
G050	H	664	48.2	9.0	19			45.4	8.5	F	B	4500	C		G
M014.1	W	689	62.0	8.5	14	ENGR	10			F	C	7220	B	W	
M014.2	W	764	70.5	5.9	8	ENGR	3			F	C	7220	B	W	
M014.7	W	807	73.8	5.7	8					F	C	7220	B	W	
M018.1	W	610	61.4	29.0	47			54.4	29.8	F	B	4500	C	W	G
M018.2	W	756	75.1	38.4	51					F	C	4500	C		O
M018.3	W		72.8	4.2	6			58.1	4.2	S	C	4500	C		
M018.4	W		37.5	5.6	15					S	C	3060	C		
M019	H	650						59.7	26.8	R	B	4498	C	W	
O019.1	W	1067	68.6	23.8	35						D	5770			
O019.10	H	771						65.8	42.3		D	5800			
O019.11	H	929						74.1	27.8		D	6640			
O019.12	H	861						50.6	13.3		D	6320			
O019.13	H	672						64.0	28.9		D	5850			
O019.14	W	1291	112.1	47.2	42						D	6200			
O019.16	W	1788	116.7	51.0	44						D	5550			
O019.17	W	1166	76.1	28.1	37						D	5700			
O019.18	W	1109	69.3	8.7	13						D	5770			
O019.19	W	816	54.4	12.2	22						D	5770			
O019.2	W	848	70.0	28.9	41						D	7100			
O019.20	W	813	62.5	17.6	28						D	6370			
O019.21	W	857	71.2	14.8	21						D	5800			
O019.22	H	1435						85.9	21.3		D	5800			
O019.23	W	1025	89.4	17.2	19						D	5720			
O019.24	W	1009	74.7	17.9	24						D	5950			
O019.26	W	1557	114.9	44.7	39						D	5600			
O019.27	W	568	48.0	15.4	32						D	6100			
O019.28	W	1064	92.9	24.0	26						D	5700			
O019.29	H	949						50.3	7.9		D	5700			
O019.3	H	1040						68.9	20.0		D	5750			
O019.30	W	995	77.4	29.1	38						D	5700			
O019.31	W	871	70.9	22.6	32						D	5750			
O019.32	W	889	58.4	20.9	36						D	5800			
O019.33	W	1012	56.7	11.3	20						D	5800			
O019.34	W	861	67.7	20.6	30						D	5700			
O019.35	H	756						48.6	20.8		D	5700			

Table A-5. European buildings data base: energy consumption (continued).

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI- DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
0019.36	W	911	64.7	26.5	41						D	6360			
0019.37	H	753						55.6	30.0		D	5700			
0019.38	W	678	70.1	17.2	24						D	6400			
0019.39	W	752	78.9	17.1	22						D	5700			
0019.4	W	1295	69.3	18.2	26						D	5400			
0019.40	W	1372	104.2	54.9	53						D	5700			
0019.41	W	1010	63.5	19.2	30						D	6080			
0019.42	W	1071	70.3	16.8	24						D	6100			
0019.43	W	909	70.0	16.7	24						D	6250			
0019.44	W	478	35.8	6.5	18						D	5900			
0019.45	W	1116	91.7	29.2	32						D	6630			
0019.46	H	957						49.5	19.0		D	5900			
0019.47	W	995	70.5	20.1	28						D	5750			
0019.48	W	1180	76.1	7.7	10						D	5900			
0019.49	W	886	67.9	17.7	26						D	5700			
0019.5	W	1288	72.4	13.7	19						D	5800			
0019.50	W	801	58.0	15.8	27						D	5550			
0019.51	W	931	95.6	28.3	30						D	6820			
0019.52	W	872	48.5	-11.0	-23						D	6370			
0019.53	W	1063	60.9	12.1	20						D	5700			
0019.54	H	1872						93.2	0.2		D	6300			
0019.55	W	1302	70.9	15.6	22						D	6300			
0019.56	W	1207	84.0	30.3	36						D	6350			
0019.57	W	1207	86.2	9.4	11						D	6350			
0019.58	W	1207	107.0	6.8	6						D	6350			
0019.59	W	1017	73.1	13.9	19						D	6390			
0019.6	H	1364						61.7	23.3		D	5550			
0019.60	W	1188	71.3	7.2	10						D	6270			
0019.61	W	1128	81.9	28.3	35						D	5700			
0019.62	H	764						38.0	8.6		D	6200			
0019.63	W	915	73.8	24.2	33						D	5700			
0019.64	W	885	54.2	3.4	6						D	5950			
0019.65	W	860	68.0	10.7	16						D	6900			
0019.66	W	1291	87.0	6.1	7						D	5600			
0019.67	H	764						34.5	3.1		D	6270			
0019.68	W	915	59.3	13.4	23						D	5650			
0019.69	W	829	50.1	6.7	13						D	6600			
0019.7	W	1255	101.4	54.1	53						D	5600			
0019.70	W	843	76.2	25.0	33						D	5400			
0019.9	W		73.3	40.7	56						D	6200			
0020.1	W	561	42.4	10.3	24						D	6000			

Table A-5. European buildings data base: energy consumption (continued).

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI-DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
0020.10	W	796	63.9	21.1	33						D	5720			
0020.11	W	852	59.7	7.9	13						D	5720			
0020.12	W	1115	62.9	10.8	17						D	6600			
0020.13	W	807	60.9	20.0	33						D	5800			
0020.14	W	1213	87.7	9.8	7						D	5560			
0020.15	W	1033	78.0	-1.4	- 2						D	5560			
0020.16	W	1173	84.5	14.5	16						D	5560			
0020.17	H	942						88.3	37.4		D	5700			
0020.18	H	897						80.7	-4.0		D	5400			
0020.19	H	861						69.7	15.1		D	6600			
0020.2	W	934	48.1	9.0	15						D	6420			
0020.20	H	861						81.4	10.9		D	7100			
0020.21	H	897						74.1	6.6		D	6600			
0020.22	H	789						70.1	3.6		D	7100			
0020.23	H	861						81.1	1.7		D	6800			
0020.24	H	888						55.6	14.9		D	5940			
0020.25	H	699						44.7	6.9		D	7550			
0020.26	H	942						58.6	5.0		D	5400			
0020.27	H	915						64.5	-2.0		D	6500			
0020.28	H	888						51.6	2.5		D	4300			
0020.29	H	753						79.4	6.0		D	4500			
0020.30	H	807						115.1	47.6		D	4500			
0020.31	H	807						37.7	10.9		D	5800			
0020.32	H	825						78.1	9.3		D	9200			
0020.33	W	885	93.3	27.8	30						D	5650			
0020.34	W	885	88.8	11.7	13						D	5650			
0020.35	H	880						47.8	3.0		D	6000			
0020.4	W	1284	55.4	13.5	24						D	5550			
0020.5	H	1006						56.9	6.9		D	5800			
0020.6	H	2015						44.5	7.4		D	5800			
0020.7	W	608	50.0	13.6	25						D	5730			
0020.8	H	899						52.4	18.1		D	6400			
0020.9	W	868	48.8	13.4	28						D	5700			
0021	H							63.0	20.3	S	C	2880	C	W	
0022.1	H	777						57.7	5.0	R	B	3928	C	W	
0022.2	H	837						69.2	7.5	R	B	3928	C	W	
0022.3	H	850						84.6	21.5	R	B	3928	C	W	
0022.4	H	850						84.6	8.9	R	B	3928	C	W	
0023.1	H	801						54.3	15.9	R	B	4498	C	W	
0023.2	H	797						54.3	1.7	R	B	4498	C	W	
0023.3	H	801						54.3	3.4	R	B	4498	C	W	

Table A-5. European buildings data base: energy consumption (continued).

BLDG. LABEL	END USES	FLOOR AREA (SQ.FT. UNIT)	NAC BEFORE (MBTU OR KWH)	NAC SAVINGS (MBTU OR KWH)	NAC SAVINGS (%)	PRED. METHOD	PRED. SAVINGS (%)	SPACE HEAT BEFORE (MBTU OR KWH)	SPACE HEAT SAVINGS (MBTU)	ANALYSIS METHOD	CONFI-DENCE LEVEL	HDD (F)	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW FUEL
O023.4	H	801						54.3	10.3	R	B	4498	C	W	
O024.1	H	577				SSHL	74	53.7	10.8	S	B	4505	C	W	
O024.2	H	570				SSHL	78	56.9	32.3	S	B	4505	C	W	
X001.1	F	802	53.9	19.3	36					R	A	6750	G	W	X
X001.1 *	F	802	34.6	3.3	10					R	A	6750	G	W	X
X001.2	F	788	50.0	9.2	19					R	A	6750	G	W	X
X001.2 *	F	788	40.7	1.2	3					R	A	6750	G	W	X
X001.2 **	F	788	39.5	3.2	8					R	A	6750	G	W	X
X001.3	F	810	51.4	7.2	14					R	A	6750	G	W	X
X001.4	F	807	54.0	9.7	18					R	A	6750	G	W	X
X001.4 *	F	807	44.3	5.1	12					R	A	6750	G	W	X
X001.5	F	807	51.2	19.4	38					R	A	6750	G	W	X
X001.6	F	807	53.2	11.0	21					R	A	6750	G	W	X
X001.6 *	F	807	42.2	-1.3	- 3					R	A	6750	G	W	X
X001.7	F	807	49.4	8.2	17					R	A	6750	G	W	X
X001.8	F	807	53.7	11.3	21					R	A	6750	G	W	X
X001.9	F	807	54.0	21.7	40					R	A	6750	G	W	X
X001.9 *	F	807	32.2	4.1	13					R	A	6750	G	W	X
X002.1	W	914	68.2	3.8	6					E	B+	8770	C	W	X
X002.2	H	900						57.1	2.3	E	B+	8770	C	W	X
X002.3	W	787	53.2	6.2	12					E	B+	8770	C	W	X
X002.4	H	870						59.6	14.9	E	B+	8770	C	W	X
X002.5	H	915						63.0	14.5	E	B+	8770	C	W	X

Table A-6. European buildings data base: retrofit characteristics.

BLDG. LABEL	RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
								($ / MBTU)			
G049.1	IR,IW,IA		82	2743	0	24.3	-776	18.69	8.95	25	C
G049.2			80	140	0	1.2	1256	1.23	9.35	15	C
G049.3			84	358	0	0.8	4802	0.81	8.95	15	C
G050	IA,IF,IW,HS	EWB	79	4074	0	65.7	-2788	44.02	7.29	15	B
M014.1	IW		77		0						
M014.2	IA		77		0						
M014.7	HC	TRV,RES	77		0						
M018.1	MC,IA,HR	HRE,BSH	79	2239	0	31.0	-974	6.09	5.02	20	B
M018.2	IA,PI,HR,HS	EWB	78	390	0	0.8	4620	0.93	10.15	15	C
M018.3	IA,IF,WR,PI,HR,WH,HS	EWB	80	514	0	27.6	-244	11.22	4.42	15	C
M018.4	IA,IF,CW,HS,HR	CEC,EWB	78	1886	0	45.4	-1163	30.94	5.18	15	C
M019	IW,WM,CW,HS,MC	BSH	77	3719	0	15.1	-1337	15.24	11.13	15	B
O019.1	IW,IA,IF,HR		82	7023	0	32.3	-3225	25.32	9.15	25	C
O019.10	IW,IF,IA,WH,HS	FEB,HWR	80	16590	0	37.1	-8796	33.65	10.56	25	C
O019.11	IW,IA,CW,HC	TRV	80	7570	0	29.8	-3133	23.36	9.15	25	C
O019.12	IW,HR,HC	RES,TRV	80	2292	0	18.8	-170	14.79	9.15	25	C
O019.13	IW,IF,IA,WM,HS,HC	FD,RES	80	5805	0	21.3	-1047	17.23	9.44	25	C
O019.14	IW,HR		81	12594	0	29.2	-5063	22.90	9.15	25	C
O019.16	IW,IA,IF,HR,HC,ID,WR,HX	RES	81	12645	0	27.1	-4508	21.28	9.15	25	C
O019.17	IW,IA,IF,HR,HC	TRV	81	9150	0	35.6	-4667	27.95	9.15	25	C
O019.18	WH,HC	RES,SHT	79	697	0	8.8	254	8.79	9.15	15	C
O019.19	IW,IA,HR		80	6079	0		-7087		9.15	25	C
O019.2	IW,IA,IF,ID,HR,CW,HC	TRV	81	12227	0	46.2	-7618	36.32	9.15	25	C
O019.20	IW,ID,WM		81	7351	0	45.7	-4543	35.85	9.15	25	C
O019.21	IW		82	4263	0	31.5	-1901	24.72	9.15	25	C
O019.22	HR,HC,WH	HWR,RES	81	2428	0	12.5	-99	12.52	9.15	15	C
O019.23	WR		80	4525	0	28.8	-1779	22.57	9.15	25	C
O019.24	IW,IA		80	4727	0	28.9	-1869	22.65	9.15	25	C
O019.26	HR,WR,IA,IF,HC	TRV	83	5616	0	13.7	1519	10.78	9.15	25	C
O019.27	HR,WR,WM,IA,IF,HC	TRV	83	3533	0	25.1	-1075	19.69	9.15	25	C
O019.28	HR,IA,IF,CW,HC	TRV	83	5061	0	23.0	-1230	18.10	9.15	25	C
O019.29	HR,IA,IF,CW,HC	TRV	83	3347	0	46.3	-2087	36.37	9.15	25	C
O019.3	IA,IW		81	3237	0	17.7	-46	13.90	9.15	25	C
O019.30	IW,IA,IF,HR,HC	TRV	83	7531	0	28.3	-2887	22.21	9.15	25	C
O019.31	HR,IW,IA		81	9167	0	44.3	-5562	34.82	9.15	25	C
O019.32	IW,IA,IF,HR,HC	TRV	82	5748	0	30.1	-2412	23.60	9.15	25	C
O019.33	HR,IW,IA,IF,CW,WR,HC	TRV	83	4742	0	45.9	-2939	36.02	9.15	25	C
O019.34	HR,IA,IF,IW,CW,HC	TRV	83	3347	0	17.8	-60	13.95	9.15	25	C
O019.35	HR,IA,IF,HC	TRV	83	3961	0	20.8	-641	16.34	9.15	25	C

Table A-6. European buildings data base: retrofit characteristics (continued).

BLDG. LABEL	RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
0019.36	WH,HC,IW,WM,WR,IA,HR	SHT,RES	80	26932	0	111.1	-22699	87.19	9.15	25	C
0019.37	CW,WR,IA,HS,IW	FD	80	431	0	1.6	2848	1.58	9.15	15	C
0019.38	IW,WM,HS	FD	79	5433	0	34.5	- 2688	27.11	9.15	25	C
0019.39	WH,OM	OMP,OMC,SET	78	35	0	0.2	1835	0.23	9.15	15	C
0019.4	HR,OM,IW,MC,HC	TRV,OMC	80	4080	0	24.5	- 1176	19.24	9.15	25	C
0019.40	HS,MC,T,HC	TRV,RES	79	518	0	1.0	5485	1.04	9.15	15	C
0019.41	IW,ID		80	4206	0	23.9	- 1142	18.80	9.15	25	C
0019.42	IW		82	9699	0	63.1	- 7018	49.54	9.15	25	C
0019.43	IW,IA		82	4598	0	30.1	- 1933	23.63	9.15	25	C
0019.44	IW		81	1146	0	19.3	- 109	15.14	9.15	25	C
0019.45	IW,IA,IF		81	3793	0	14.2	867	11.15	9.15	25	C
0019.46	IW,IA,IF,ID		82	9161	0	52.7	- 6129	41.37	9.15	25	C
0019.47	IW,HC,IA	RES	79	4201	0	22.8	- 993	17.93	9.15	25	C
0019.48	IW		82	5269	0	74.8	- 4040	58.71	9.15	25	C
0019.49	IW,IA		80	5853	0	36.1	- 3027	28.37	9.15	25	C
0019.5	IW,WM,HR,HC	RES	81	6897	0	55.0	- 4713	43.22	9.15	25	C
0019.50	IA,IF		82	1273	0	8.8	1249	6.91	9.15	25	C
0019.51	IW,WR,IA,HC	TRV	81	4931	0	19.0	- 415	14.96	9.15	25	C
0019.52	IW,IA,IF		82	3736	0		- 5492		9.15	25	C
0019.53	HR		80	2210	0	20.0	- 887	20.05	9.15	15	C
0019.54	HR,HC	TRV	82	3139	0	1715.5	- 3117	1723.29	9.15	15	C
0019.55	HR,HC	TRV	81	1304	0	9.1	402	9.18	9.15	15	C
0019.56	HS		82	494	0	1.8	2820	1.79	9.15	15	C
0019.57	HR,HC	RES	79	814	0	9.5	213	9.51	9.15	15	C
0019.58	HR		79	1645	0	26.4	- 902	26.57	9.15	15	C
0019.59	ID,HR,HC	RES	82	1417	0	11.1	103	11.19	9.15	15	C
0019.6	MC,HC,CW,IA,IW,IF,HR	TRV	81	10166	0	47.7	- 6450	37.45	9.15	25	C
0019.60	HS,WH	FD,SHT	81	443	0	6.6	361	6.76	9.34	15	C
0019.61	HR,WH	HWR	81	1591	0	5.8	1666	6.17	9.62	15	C
0019.62	HR,HC,ID,WM	RES	82	1647	0	20.9	- 706	21.02	9.15	15	C
0019.63	HR,WH	HWR	77	1047	0	4.7	1599	4.75	9.15	15	C
0019.64	HS,OM	OMC,FD	81	275	0	8.9	96	8.91	9.15	15	C
0019.65	HS	FD	82	1286	0	13.1	- 116	13.19	9.15	15	C
0019.66	HS	FD,RES	82	223	0	4.0	445	4.00	9.15	15	C
0019.67	HC,ID,WM,HS	FD,RES	81	173	0	6.1	167	6.10	9.15	15	C
0019.68	HS,ID,WH	FD,HWR	79	386	0	3.1	1080	3.16	9.15	15	C
0019.69	HS	FD	79	134	0	2.2	599	2.20	9.15	15	C
0019.7	HR,MC,IF		81	3136	0	6.3	5500	4.98	9.15	25	C
0019.70	IF,IA,HC	TRV	82	1632	0	7.1	2358	5.60	9.15	25	C
0019.9	HS	FEB	80	6474	0	20.3	- 2665	17.46	9.15	15	C
0020.1			78	265	0	2.8	861	2.83	9.15	15	C

Table A-6. European buildings data base: retrofit characteristics (continued).

BLDG. LABEL	RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
0020.10			84	4722	0	24.5	- 1355	19.21	9.15	25	C
0020.11			84	1649	0	22.8	- 389	17.92	9.15	25	C
0020.12			82	2622	0	26.5	- 898	20.83	9.15	25	C
0020.13			83	10460	0	57.2	- 7269	44.88	9.15	25	C
0020.14			80	113	0	1.1	1072	1.27	10.12	15	C
0020.15			80	194	0		- 368		10.43	15	C
0020.16			80	388	0	2.6	1411	2.94	10.38	15	C
0020.17			78	5394	0	15.8	574	12.38	9.15	25	C
0020.18			78	1624	0		- 2262		9.15	25	C
0020.19			79	840	0	6.1	1570	4.77	9.15	25	C
0020.2			84	3348	0	40.7	- 1913	31.94	9.15	25	C
0020.20			80	2424	0	24.3	- 684	19.07	9.15	25	C
0020.21			79	448	0	7.4	273	7.46	9.15	15	C
0020.22			80	1077	0	32.7	- 683	32.85	9.15	15	C
0020.23			80	3447	0	221.7	- 3175	173.97	9.15	25	C
0020.24			78	1392	0	10.2	237	10.26	9.15	15	C
0020.25			79	4369	0	69.2	- 3268	54.33	9.15	25	C
0020.26			79	1344	0	29.4	- 547	23.08	9.15	25	C
0020.27			80	1293	0		- 1612		9.15	25	C
0020.28			81	5918	0	258.7	- 5520	203.17	9.15	25	C
0020.29			81	3035	0	55.3	- 2078	43.43	9.15	25	C
0020.30			80	11635	0	26.7	- 4037	20.97	9.15	25	C
0020.31			80	17291	0	173.4	-15549	136.10	9.15	25	C
0020.32			79	3809	0	44.8	- 2325	35.14	9.15	25	C
0020.33			80	1320	0	5.2	3116	4.07	9.15	25	C
0020.34			80	452	0	4.2	1415	3.31	9.15	25	C
0020.35			85	2630	0	84.8	- 2089	75.23	10.34	25	C
0020.4			84	3692	0	29.9	- 1538	23.48	9.15	25	C
0020.5			85	107	0	1.7	648	1.70	9.15	15	C
0020.6			85	836	0	12.3	345	9.69	9.15	25	C
0020.7			82	1165	0	8.4	1258	7.35	10.21	25	C
0020.8			83	3586	0	21.7	- 697	17.00	9.15	25	C
0020.9			81	2289	0		- 3311		9.15	15	C
0021	IA,IF,CW,HS,HR,IW,HC,OM	TUR,CEC,HRE,TRV,EWB	79	1111	0	4.9	1468	5.16	11.12	20	B
0022.1	HC	TRV	77	209	0	6.7	19	5.97	6.22	10	B
0022.2	IA,IW		77	3771	0	80.9	- 3239	47.47	6.22	20	B
0022.3	IW,IA,WM		77	10887	0	81.5	- 9362	47.81	6.22	20	B
0022.4	HC	RES	77	650	0	11.7	- 244	10.40	6.22	10	B
0023.1	HC	RES	77	552	0	3.1	747	4.95	11.13	10	B
0023.2	WM,HC,MC,CW	TRV	77	1519	0	80.3	- 1344	102.17	11.13	14	B
0023.3	MC		77	213	0	5.6	65	8.93	11.13	10	B

Table A-6. European buildings data base: retrofit characteristics (continued).

BLDG. LABEL		RETROFIT MEASURES	HEAT SYSTEM MEASURES	YR OF RETRO FIT	RETRO. COST (87$)	MAINT. COST ($/UNIT)	SIMPLE PAYBACK (YEARS)	NPV ($/UNIT)	CCE	ENERGY PRICE (1987 $)	RETR. LIFE TIME	CONF. LEVEL COST
O023.4		HC,MC	TRV	77	411	0	3.6	431	5.68	11.13	10	B
O024.1		IF,IA,IW,HS	EWB	78	1128	0	9.4	169	10.39	11.13	18	B
O024.2		IW,IF,IA,WM,HS	EWB	78	7125	0	19.8	- 3246	21.93	11.13	18	B
X001.1		IA,OM,CW,WH,HC,IX,IW	OMC,LFS,TRV	83	9513	18	39.3	- 5823	47.44	13.56	20	A
X001.1	*	WM		84	1167	0	26.1	- 500	33.36	13.56	20	A
X001.2		IA,OM,CW,WH,HC	OMC,LFS,TRV	83	1226	18	11.7	81	16.59	13.56	15	A
X001.2	*	IX		83	604	0	37.1	- 362	47.50	13.56	20	A
X001.2	**	WM		84	1236	0	28.5	- 590	36.46	13.56	20	A
X001.3		IA,OM,CW,WH,HC	OMC,LFS,TRV	83	1157	16	14.5	- 155	19.88	13.56	15	A
X001.4		IA,OM,CW,WH,HC,IX	OMC,LFS,TRV	83	1546	17	13.7	215	16.79	13.56	20	A
X001.4	*	HS		84	1962	91		- 2024	60.07	13.56	15	A
X001.5		IA,OM,CW,WH,HC,IX,IW	OMC,LFS,TRV	83	9011	17	36.9	- 5289	44.70	13.56	20	A
X001.6		IA,OM,CW,WH,HC	OMC,LFS,TRV	83	1063	16	8.1	556	12.07	13.56	15	A
X001.6	*	IX		83	574	0		- 837		13.56	20	A
X001.7		IA,OM,CW,WH,HC,WM	OMC,LFS,TRV	84	2202	17	23.7	- 739	27.42	13.56	20	A
X001.8		IA,OM,CW,WH,HC	OMC,LFS,TRV	83	1096	16	8.1	571	12.07	13.56	15	A
X001.9		IA,OM,CW,WH,HC,IX,IW,WM	OMC,LFS,TRV	83	10692	17	38.8	- 6504	47.27	13.56	20	A
X001.9	*	HS		84	1962	91		- 2186	74.72	13.56	15	A
X002.1		HC,OM	TRV	82		0				13.28	5	C
X002.2		WM		84		0				13.28	20	C
X002.3		HX		84		0				13.28	20	C
X002.4		HS		84		0				13.28	20	C
X002.5		HS		84		0				13.28	20	C

APPENDIX B: SUMMARY OF RETROFIT PROJECTS IN EXISTING MULTIFAMILY BUILDINGS

Appendix B contains a brief description of each retrofit project included in this study. For each project, we include a brief physical description of the building(s), installed conservation measures, data quality and analysis techniques, as well as energy savings and cost-effectiveness of the retrofit. Each data source is identified by a label that indicates the fuel used for space heating (e.g., electricity (E), gas (G), oil (O), mixed (M), and district heating (X)) as well as the location and sponsor of the retrofit project.

GAS HEAT

G031.1 - G031.8: Chicago, IL - Center for Neighborhood Technology [1]

Building/Retrofit Description: This study details changes in energy consumption that occurred in eight cooperatively-owned multi-unit buildings after the installation of a series of retrofit measures. The buildings range in size from four to 25 units and are all three-story, 70 year-old structures with built-up roofs, masonry bearing walls, and single-pipe steam heating distribution systems. Attic insulation (equivalent of R-40) and storm windows were installed at four of the buildings. The heating system measures included de-rating and tuning burners in oversized heating systems (8), replacing burners (2), installation of air temperature-sensing burner controls with programmable setbacks (4), high-limit outdoor stats (7), flue dampers (3), and balancing radiators and steam lines (8).†

Data/Analysis: We reports results for each building separately in this study, including data on measures installed, cost of retrofits, and gas usage before and after retrofit. Katrakis estimated man-hours for each retrofit and calculated labor costs based on mid-1982 labor rates (i.e., $40/hour, the current rate charged by a heating contractor), because many of the heating system retrofits were do-it yourself projects initiated by coop building maintenance staff. Annual maintenance costs were estimated at $50/apt for the retrofit package.

Results: Annual space heat savings were between 25-58 MBtu/unit in six of the eight buildings. The authors estimate that approximately 60% of the savings are attributable to various heating system retrofits, which were particularly cost-effective.

G032: Newark, NJ - Bumblebee Energy Systems [2]

Building/Retrofit Description: A computerized energy management system was installed by Bumblebee Energy Systems in a 530-unit family apartment complex operated by Newark Housing Authority. The system monitors indoor apartment temperatures, and supplies heat by opening and closing motorized valves depending on the average of apartment temperatures in each building. During the same time period, the central heating plant was totally refurbished, which complicates analysis of the energy savings attributable to the energy management system. The heating plant refurbishment included installation of new boilers, underground piping, control valves, and a separate gas-fired hot water generator.

Data/Analysis: Based on an analysis of several years' consumption data at four other projects, Bumblebee Management concluded that the heating plant modernization did not yield any significant savings. Any potential efficiency improvements were overshadowed by impacts stemming from the proper or improper operation and maintenance of the heating plant and control systems. They apportioned the 26% total annual savings as follows: one-half to replacement of the condensate lines (part of the modernization) and one-half to the Bumblebee energy management system. LBL used summer months usage to estimate baseload consumption; the estimated space heat portion of total gas consumption was then normalized to a 'typical' heating season. An annual operating and maintenance cost of $25,000/year or $40/apartment unit was included in the economic calculations (Bumblebee's estimated cost for a service contract for the control system).

† Number in parentheses indicates buildings that received the measure.

Results: LBL used the 14% savings allocated to the energy management control system and the associated cost in estimating savings and cost-effectiveness (disregarding changes in consumption attributable to the refurbishment of the heating plant). The retrofit had a simple payback period of approximately three years and an internal rate of return of 39%.

G035.1 - G035.6: San Francisco, CA - San Francisco Housing Authority [3]

Building/Retrofit Description: In 1982, the San Francisco Housing Authority began trying to reduce rapidly increasing energy expenses by installing attic insulation, exterior door weather stripping, low-flow showerheads, and water heater blankets in the buildings that it manages. The conservation measures were financed by the local utility's zero-interest loan program (ZIP). The impact of the program was evaluated at five multifamily housing projects (totalling 1822 units). Each project consists of many 10-20 unit low-rise buildings. Two of the projects have individual unit space heaters, while gas-fired central boilers supply space heat and hot water at the other three projects. These five projects are occupied by families and are master-metered; thus tenants do not pay utility costs directly.

Data/Analysis: LBL used the Princeton Scorekeeping Method (PRISM) to analyze three years of utility bills provided by SFHA (includes one year of data after the retrofit). To adjust for occupancy effects, LBL divided total project gas use during each billing period by the number of occupied units in that period.

Results: Cooking energy use was metered separately at two projects, Hayes Valley and Potrero Terrace, and accounts for a surprisingly large fraction (19 to 29 percent) of total gas consumption. Weather-normalized annual natural gas consumption declined by 13 percent after the retrofit at the five projects; net savings relative to a comparison group were eight percent. Most of the energy savings resulted from reduced baseload usage. Pre-retrofit energy use appears to be a major influence on the savings produced by the ZIP measures. Overall, the retrofit program was cost-effective, with a net present value of $399,000 or $220/unit. The Housing Authority's careful efforts to control retrofit costs, which averaged only $150/unit, contributed to the program's success.

G035.11 - G035.16: San Francisco, CA - San Francisco Housing Authority [4,5]

Building/Retrofit Description: Solar domestic hot water systems were installed in the spring of 1984 at six senior properties managed by the San Francisco Housing Authority. This relatively expensive conservation option was financed by third-party investors, who own the solar equipment and sell hot water to the Housing Authority in a micro-utility arrangement. The projects use natural gas for space heat and domestic hot water while electricity is used for cooking. Domestic hot water at each project is supplied by a central boiler.

Data/Analysis: LBL used one year of pre- and post-retrofit gas bills, along with Btu meter readings of the energy produced by the solar systems. The number of occupied units were also available for the entire analysis period. Energy savings increased when consumption data were adjusted for the number of occupied units during that billing period.

Other minor retrofits, including low-flow showerheads and weatherstripping, were installed several months before the solar hot water system at all projects except 3850 18th Street. Due to the timing of these retrofits, it is not possible to isolate the solar hot water system retrofit, hence savings estimates include these minor retrofits. In addition, savings estimates at two projects, 499 31st Avenue and 939 Eddy Street, include the effects of the solar system and a boiler time-clock retrofit which was installed in October 1982.

Results: The Btu meter readings suggest that the solar system retrofit reduced gas consumption by between 8 and 13% of pre-retrofit levels at each of the projects (including an assumed furnace efficiency factor of 0.6). However, comparisons of weather-normalized consumption before and after retrofit at each project suggests that system performance is more variable or that other factors have a confounding influence. At three projects (3850 18th, 1760 Bush, and 2698 California), the normalized annual consumption (NAC) remained relatively unchanged before and after installation of the domestic solar hot water system. The lack of savings at 1760 Bush, a seven-story concrete-block building completed in the early 1970s, may be due to the low tilt angle (5^{o}) of the collector plates. In addition, all three of these projects had longer pipe runs (and presumably greater standby losses) compared to buildings with significant reductions in energy consumption. Weather-adjusted annual gas consumption decreased by 10, 13, and 23 percent at the other three projects.

G036.1 - G036.5: Hightown, NJ - Princeton Center for Energy and Environmental Studies [6]

Building/Retrofit Description: Princeton's Center for Energy and Environmental Studies (CEES) reported on retrofit efforts in a garden apartment complex in New Jersey. The complex consists of 40, two-story, brick buildings (480 units), with R-30 roof insulation, and 20 gas-fired firetube boilers with tankless coil heat exchangers for domestic hot water that each serve a cluster of one to three buildings. Because of data problems, LBL focused on two sets of retrofits: reduction in boiler water temperature and installation of separate hot water boilers in three buildings and heating system controls in two buildings.

Data/Analysis: LBL adjusted Princeton's estimates of space heat consumption (given in Btu/ft^2-DD) to gas usage in a normal year for that climate (i.e., 4872 HDD). Annual estimates of baseload usage were derived from DHW consumption during the summer months.

Results: Detailed monitoring by CEES of the hot water distribution system in two identical buildings showed that hot water use was 2.5 times greater in one building than the other building and that seasonal efficiency was quite low. Average gas consumption was reduced by 19% in three buildings that received a separate boiler for hot water and in which boiler water temperature was lowered from 190 to 170°. Space heat savings ranged between four and 23 percent in the two buildings that installed heating system controls to cycle the space heat pumps. Retrofits to the domestic hot water system were particularly cost-effective in these buildings, with payback times of about one year.

G037.1 - G037.7: Minneapolis, MN - Minneapolis Energy Office/ Self-Reliance Center [7]

Building/Retrofit Description: The City of Minneapolis and the Self-Reliance Center investigated the conversion of steam heating systems to modern hot water heating systems in seven multifamily buildings constructed before World War II. In two-pipe systems, the existing distribution system was nearly always maintained. In single-pipe systems, the retrofit included re-piping the distribution system, replacing of steam-only radiators, conversion from single to multi-zone, and installation of reset controls.

Data/Analysis: LBL made several adjustments to the original analysis performed by the study authors: 1) normalized energy use by number of occupied units during the pre- and post-retrofit period, and 2) our economic analysis included annual operations and maintenance costs (estimated at -$20/unit) and used incremental costs in two buildings that had to replace boilers (i.e., total cost of conversion minus cost of steam boiler replacement).

Results: In most of the buildings, gas savings were approximately 20-25 percent with fairly long simple payback times (10-20 years) if total retrofit costs are included. In two buildings where the steam boiler needed to be replaced (one single-pipe and one two-pipe), the incremental costs were small; and the retrofit was quite effective. Retrofit cost and cost-effectiveness were strongly correlated with the type of steam system (i.e., single-pipe steam conversions were more expensive than conversions of two-pipe steam systems). Interviews with building owners indicate that the retrofit helped correct uneven heating problems and reduced maintenance problem in addition to the energy savings.

G038.1 - G038.17: Minneapolis, MN - Minneapolis Energy Office [8,9]

Building/Retrofit Description: The Minneapolis Energy Office (MEO) and Minnegasco tested outdoor resets and cutout controls in two groups of modern, hydronically heated apartment buildings. The first group of buildings was retrofitted in 1982, and closely monitored by MEO staff. Initial retrofit costs were quite low ($10-20/unit). In 1984, eight additional buildings were retrofitted as part of the Multifamily Pilot Project (sponsored by MEO and Minnegasco). The same controls were installed in these buildings, however, contractors were not supervised by the MEO staff. Retrofit costs were slightly higher in this group ($20-60/unit), partly due to the fact that these buildings had fewer apartments. The buildings are all three-story walkups, range in size from 4900 to 38000 ft^2, and were constructed in the mid-1960s and early 1970s. They have wood-frame construction with lightly insulated walls and roofs, include double-glazed windows, and have central heating and domestic hot water systems.

Data/Analysis: For the first group of nine buildings, MEO collected sub-metered space heat data and weekly inside temperature readings on four buildings; whole-building utility billing data was available on the remaining five buildings. In the submetered buildings, the heating systems were run alternatively with constant temperature control and reset/cutout control at two week intervals over two heating seasons. The second group of eight buildings are all master-metered. MEO used PRISM to analyze whole-building gas utility bills that included space heat, domestic hot water, and some cooking. LBL used results obtained from MEO's energy analysis.

Results: In the first group of buildings, space heat consumption decreased by about 10 percent, while the economics of the retrofit were very attractive (roughly one year payback). Based on results from the first study, the authors concluded that an outdoor reset is probably the most cost-effective retrofit for hydronically heated apartment buildings with cast-iron boilers. NAC savings ranged from 0 to 18 percent in the eight additional buildings, while payback times were under three years in six of the eight buildings. MEO staff think that non-ideal reset ratios may have contributed to the somewhat lower savings in the second sample.† MEO is currently investigating an audit diagnostic technique that will determine the ideal reset ratio for a given building.

G039: Asbury Park, NJ - Princeton Center for Energy and Environmental Studies [10,11]

Building/Retrofit Description: Princeton University's Center for Energy and Environmental Studies evaluated a series of retrofits that were installed at Lumley Homes over the last four years. Lumley Homes project includes two six-story buildings with a total of sixty units and 75 elderly occupants. Gas is used for space heating, domestic hot water, and cooking.

Data/Analysis: LBL aggregated the five retrofits that took place during the study period into two retrofit interventions so that adequate consumption data were available before and after each retrofit. The first retrofit intervention included new Dunham-Bush zone controls for the steam distribution system and a vacuum pump (installed in December 1981) as well as a separate boiler for summer domestic hot water heating (a Weil-McLain boiler with an input rating of 430 kBtu/hour installed in April 1982). The second retrofit intervention includes interior storm windows and new steam traps (October 1983) and a series of no-cost changes in the operation of the heating plant (steam pressure and controller settings lowered, radiators opened, and night setback hours extended--March and April 1984). The results of PRISM runs performed by Princeton were used to calculate energy savings from both sets of retrofits.

Results: Energy use did not change significantly after the first retrofit intervention. Observation of the zone controls showed that they were set to send 25% of the steam to each of the four building zones--probably not the optimal setting. The separate domestic-hot-water boiler, however, did decrease the amount of baseload energy used. NAC decreased by 40% after the second retrofit intervention, giving a simple payback time of about two years.

G040.1 - G040.10: Minneapolis, MN - Minneapolis Energy Office [12]

Building/Retrofit Description: The Minneapolis Energy Office (MEO) collected and analyzed energy data on ten Minnesota buildings in which building owners installed a tenant metering system. All buildings had hot water baseboard heating systems and individual zone control of the flow of hot water into each apartment. Prior to the installation of the new metering system, energy costs were included in the rent in these master-metered buildings. The new metering system divides the energy bill among individual apartments on the basis of use. The metering equipment consisted of time meters which recorded the number of hours that the thermostat called for heat or the number of hours that the zone valve was open; hence the meter does not actually measure the amount of heat delivered. The installed cost for the system ranged from $70 to 120/unit with an annual service charge of approximately $15-18/year.

Data/Analysis: MEO used PRISM to analyze utility bills for the entire building before and after the installation of the tenant metering system.

Results: After the new system was installed, gas consumption decreased by 15-18% compared to pre-retrofit levels. This retrofit strategy was very cost-effective from the perspective of the building owner yielding payback times between one and five years. The effect of tenant metering on the individual tenants depends on whether or not the building owner reduces rents to account for his lower operating expenses. If this retrofit is implemented without a rent reduction, the tenant's total costs can increase significantly.

† The reset ratio is the ratio of the change of outdoor temperature to the resulting change of boiler water set point temperature. The proper reset ratio is building-dependent and controlled primarily by the installed design condition water temperature.

G041.1- G041.5: Chicago, IL - University of Illinois at Chicago [13]

Building/Retrofit Description: The Energy Resources Center at the University of Illinois at Chicago (UIC) conducted an evaluation of the Chicago low-income weatherization program, Their sample consisted of over 60 buildings/houses that were retrofitted in 1981 and 1982. LBL included five low-rise buildings with five or more units from their study. Retrofits at these sites included permanent storm windows, storm doors, attic insulation, and/or caulking and weatherstripping.

Data/Analysis: UIC's energy analysis technique was similar to PRISM, linear regression of gas use versus daily average outside temperature using variable base heating degree-days. Retrofit costs and energy prices provided by UIC were used by LBL to calculate cost-effectiveness indicators.

Results: NAC savings varied greatly (between -4% to 26%), even among buildings that received identical retrofits. Economic indicators were correspondingly disparate, with payback times ranging from 5 to 40 years. Lack of information and poor data quality limit our ability to explain the wide variation in retrofit performance (e.g., analysts were unable to conduct site visits or interview building managers or tenants).

G042.1 - G042.6: Minneapolis, MN - Minneapolis Energy Office [14]

Building/Retrofit Description: The Minneapolis Energy Office conducted a field test of vent damper performance in six low-rise multifamily buildings. Four buildings were tested in an on/off experiment during the 1984/85 heating season. Custom-made electronic vent dampers were installed in the boilers used for space heating at each of these buildings. Two of the buildings had large brick-set site-built steam gas-fired boilers with large vents connected to brick masonry chimneys. The other two buildings had gas-fired, atmospheric, hydronic boilers connected to large chimneys; here, dampers were also installed on the domestic hot water heaters, as much of the heat retained by the boiler dampers could otherwise be lost via the water heater vent. All boilers used electronic ignitions which allowed the vent dampers to be tightly closed. During the 1985/86 heating season, two more hydronically heated buildings were fitted with space heat and hot water boiler dampers, and the water-heater boiler dampers were added to the steam-heated buildings to see what additional savings could be realized.

Data/Analysis: The heating systems were run alternatively with the vent dampers operating and then deactivated at two week intervals throughout the 1984-85 heating season. During the 1985-86 heating season, one week intervals were used to test three different operating modes: no dampers, dampers for space heat boilers, and dampers for space heat and hot water systems. MEO collected submetered space heat energy use data by installing on-time meters to record the burner firing time along with measurements of boiler firing rates (which were fixed). MEO then used PRISM to analyze consumption data taken during the heating season in different operating modes to obtain an estimate of the impact of the vent dampers. For the buildings with two years of experimental data, LBL used an average of space heat use during the on/off periods in both heating seasons as pre- and post-retrofit consumption. LBL did not include results from the water heater dampers installed at the steam-heated buildings during 1985/86, so that the performance of the space heat dampers could be tracked over the course of two heating seasons.

Results: The four buildings which were tested for two years displayed surprising results. First-year space heat energy savings ranged between 10 to 15 percent. Actual savings were higher than predicted estimates, particularly in the two buildings with boilers with draft diverters. In the second year, however, consumption and savings varied significantly: at one building, savings between the on and off modes increased to 18%, while lower savings (2-10%) were realized at the remaining buildings. MEO believes that the use of a one-week analysis period, and three testing modes, may have contributed to the instability of the second-year results. Neither the absolute savings nor the changes between the first and second years of testing are easily explained by the buildings' physical characteristics. Because the savings from this retrofit result from boiler room heat being exchanged with living spaces, savings could be thought to correlate with the amount of contact between boiler rooms and living spaces. However, boiler rooms at all buildings except G042.5 were well sealed off from the living spaces by masonry walls and fire doors, but only at G042.5, where the boiler room is part of a laundry room which opens onto a hallway, did energy use increase after damper installation. While G042.3 and G042.4 had high turnover rates between 1984 and 1986 (88% and 43% respectively), vacancies are known to have been very low, and only minor physical changes were made to any of the buildings during the testing period. Vent dampers on the space heat boiler of the steam-heated buildings had payback times of two years. At one hydronically heated building, energy consumption increased after the retrofit, while payback times at the three remaining buildings ranged from 6 to 39 years.

G043: Atlanta, GA - Heery Energy Consultants, Inc. [15]

Building/Retrofit Description: St. Charles Condominium is an older, 16-unit, steam-heated building that uses master-metered gas to produce domestic hot water and steam for space heating. In December 1982, a micro-computer-driven boiler on-off control was installed to address problems of overheating and excessive consumption. This device uses exterior temperature to regulate the amount of time that the boiler is enabled. The computer control system was installed for the relatively low cost of $580, due to free programming and installation by a resident of the building.

Data/Analysis: LBL's economic analysis used an estimated commercial price for an equivalent system of $2000. Annual maintenance costs of $800 ($50/unit) were projected by the installer of the system. LBL used PRISM to analyze monthly gas utility bills provided by the building manager.

Results: The initial control parameters used in the computer caused uncomfortably cold conditions inside the apartments. Comfort improved after the settings were changed, and annual savings of 43 MBtu/unit were achieved over a two-year period since installation of the system (a 32% decrease from pre-retrofit normalized annual consumption). The domestic-hot-water boiler was also replaced during the post-retrofit period (mid-1984) with a high-efficiency model, although energy consumption levels did not change after this measure. This retrofit was very cost-effective, with a simple payback time of less than one year (which includes use of the higher commercial cost for the system).

G044.1 - G044.2: Phillipsburg, NJ - Phillipsburg Housing Authority [16]

Building/Retrofit Description: Between 1980 and 1983, two gas-heated, low-rise housing projects, Heckman Annex and Heckman Terrace, were rehabilitated and retrofitted. Major structural renovation at Heckman Annex (G044.1) included a new insulated facade and new roofs with eight inches of insulation along with the following conservation retrofits: thermopane windows, replacement of existing doors with insulated doors, storm doors, three inches of crawl space insulation, maximum set thermostats, boiler controls, and new boiler valves. At Heckman Terrace (G044.2), major structural rehabilitation work included an insulated exterior facade and replacement of twenty-year-old gas warm-air furnaces with Lennox furnaces in each apartment. Conservation measures include thermopane windows, new doors, and maximum set thermostats.

Data/Analysis: LBL used PRISM to analyze monthly utility bills provided by the Housing Authority. The Phillipsburg Housing Authority was unable to provide LBL with costs for the conservation measures alone, nor was it able to quantify decreased maintenance costs based on the rehab.

Results: Energy use decreased drastically at both projects following the rehabilitation work--normalized annual consumption dropped by 41% at Heckman Annex and 53% at Heckman Terrace. However, the rehab has very long payback times (greater than 25 years) if evaluated strictly as an energy conservation measure, because the project was very expensive (over $12,000/unit). Housing Authority staff cited reduced window breakage following replacement as an additional benefit that derived from this project.

G045.1 - G045.13: Minneapolis, MN - Minneapolis Energy Office [17,18]

Building/Retrofit Description: During the summer of 1984, Minneapolis Energy Office (MEO) and Minnegasco sponsored a Multifamily Pilot Project (MFPP) to demonstrate a cost-effective package of retrofits in multifamily buildings with five or more units. As part of that project, thirteen low-rise buildings with single-pipe steam heating distribution systems received a "steam balancing" retrofit, which included several measures. All buildings received new boiler controls which effectively lengthened the boiler cycle through the use of a pressure-sensing control; larger radiator vents or thermostatic radiator vents were also added where necessary. In all but one building, larger main-line air vents were installed (to allow all air to be vented from the steam line). Boilers were cleaned and tuned at three of the sites. All buildings used gas for space heat, domestic hot water, and cooking; seven also have gas dryers in their laundry facilities. The buildings are similar in that they are fairly old (built between 1911 and 1930) and have central space heat and domestic hot water systems with gravity-circulated single-pipe steam.

Data/Analysis: MEO used PRISM to analyze gas utility bills before and after the retrofit.

Results: Gas savings averaged 10%, although savings varied greatly among these buildings (from -15 to 20%). Discussion with the tenants of the building in which consumption increased after balancing indicate that the building was severely underheated prior to retrofit, suggesting that building average temperatures may have actually increased after balancing. Retrofit costs averaged about $100/unit (1987$), ranging from $30-270/unit. Payback times were under two years in ten of the thirteen buildings. Savings were not highly correlated with either the amount spent or consumption levels prior to retrofit. The study authors found that energy savings are most influenced by the degree of uneven heating in individual units and the building's average temperature. Savings occur in an overheated building because the net affect of balancing will be to reduce overall building temperatures. The authors also note that building owners reported that the comfort of tenants improved greatly as a result of these retrofits. Measured savings exceeded predicted savings (15 vs. 10%) in a subset of nine buildings.

G046: Asbury Park, NJ - Princeton Center for Energy and Environmental Studies/Asbury Park Housing Authority [19]

Building/Retrofit Description: A twelve-building public housing complex in Asbury Park, New Jersey was converted from central to individual space heat and domestic hot water systems in the fall of 1983. The original system had steam and domestic hot water distribution through underground piping; the space heat boiler provided steam for domestic hot water production. The Asbury Park Housing Authority decided to replace the system because of leaks in the condensate return lines, a degenerated vacuum pump, and high maintenance costs. The new equipment included Heat Controller furnaces, rated at 80 kBtu/hr input, individual unit water heaters sized at 30-40 gallons, vents, ducts, thermostats, and gas and water piping. The conversion cost was about $3200/apartment. Furnaces, ducts, vents, and thermostats represented 60% of the costs; plumbing accounted for 37% and water heaters only 3% of the total.

Data/Analysis: Researchers at Princeton's CEES used master-metered gas utility bills (for space heat, domestic hot water, and cooking) to analyze consumption before and after the retrofit. Prior to the conversion, consumption for the whole complex was recorded on one meter; after the new heating systems were installed, meters were placed on each of the twelve buildings. Therefore, pre-retrofit PRISM runs use aggregate consumption, while the post-retrofit figures are based on the average of results for the individual buildings. LBL estimated that the retrofit would reduce maintenance costs by about $100/unit (i.e., $12500/year or 300 man-hours).

Results: Energy consumption was reduced drastically by the heating system conversion: normalized annual consumption decreased by 52%. The large savings were attributable to reduced overheating, elimination of heat losses through the underground piping, increased furnace efficiency, and better indoor temperature control. The retrofit had a five year payback time.

G047.1 - G047.12: St. Paul, MN - St. Paul Energy Resource Center [20,21]

Building/Retrofit Description: The Energy Resource Center (ERC) has implemented an extensive shared savings financing program, with a total investment of over $450,000 through 1985. ERC selected twelve buildings representative of those included in the shared savings program in order to evaluate energy savings and assess the accuracy of predicted estimates. All buildings were two or three stories; most of the occupants were young single adults, with elderly residents accounting for 20% of the population. Distribution systems included single-pipe steam, double-pipe steam, and hot water. Retrofit costs ranged from $300 to $1500 per unit and included the following measures: attic insulation; wall insulation; window replacement, insulation, or sealing; and a variety of heating plant alterations, including front-end boilers, vent dampers, conversion from double-pipe steam to hot water distribution, and balancing of single-pipe steam systems. Incremental maintenance costs of $300/year-project were assumed by ERC. This represents ERC time for inspection and advice, and not time required by building staff to carry out ERC's maintenance recommendations. ERC believes that no additional building staff time will be required to maintain the new equipment.

Data/Analysis: LBL excluded one building in the study, a "board and care" home for the elderly that was not apportioned into apartments, from the data base. ERC used PRISM to analyze two years of gas utility bills that included the following end uses: space heat, domestic hot water, and dryers. In addition, at five buildings, space heat and/or domestic hot water gas consumption were sub-metered and read bi-weekly as part of an on/off experimental design. This design was used to evaluate the following retrofits: performance of high-efficiency front-end boilers versus existing boiler and tank-type water heaters (St. Clair and Summit buildings), electric vent dampers (Grand building), step vs. simultaneous firing of two high-efficiency boilers (Laurel building), and a high-efficiency DHW pulse-combustion boiler versus a tank-type water heater (Goodrich building).

Results: Energy consumption decreased by 22% in three buildings that received steam balancing along with other measures, while usage declined by 46% in four buildings that converted the heating distribution system from steam to hot water in conjunction with other measures. Front-end boilers reduced space heat and hot water consumption at St. Clair building by seven percent, while space heat energy consumption declined by 15% at the Summit building. ERC notes that control problems contributed to the suboptimal savings at St. Clair. Both the vent damper and the step-firing control paid back in about one year; the expensive pulse boiler saved 31% of domestic hot water use, with a 13 year payback. On average, actual savings were comparable to predicted estimates (33% in the 12 buildings), although there was much less agreement at the individual building level.

G048.1 - G048.7: Chicago, IL - Chicago Energy Savers Fund [22]

Building/Retrofit Description: The Chicago Energy Savers Fund (CESF) is a subsidized loan program sponsored by Peoples Gas and the City of Chicago that is targeted to low and moderate income residential gas customers. The program finances the installation of major conservation measures to owners of low-rise multifamily buildings with less than 50 units. Typically, the buildings are three-story walkups with flat roofs, masonry walls, double-hung wood windows, and gas-fired central boilers with a single-pipe steam distribution system. Retrofit costs varied between $400 and $2400 per unit; smaller buildings tender to have higher per unit costs. Storm windows were also installed in the two buildings with the highest costs. Heating and hot water system retrofits were particularly popular (e.g., vent dampers, outdoor cutoff, balancing of the steam distribution system, and thermostats). In addition, attic insulation was installed in five of seven buildings.

Data/Analysis: The Energy Savers Fund sent information on 17 buildings that have been retrofitted under the program including, in most cases, an energy audit, measures installed and their cost, and utility bills before and after retrofit. LBL included seven of these buildings in the data base; buildings were omitted either because of inadequate information on measures installed and retrofit cost, too short a period after the retrofit, or insufficient number of actual meter readings. LBL used data supplied by CESF on the number of days and heating degree-days during the pre- and post-retrofit period, along with CESF's breakdown of gas consumption for space heating and domestic hot water to estimate gas consumption in a year with typical weather. LBL scaled gas used for space heating in each period by the ratio of normal to actual year heating degree-days.

Results: Prior to retrofit, gas usage was relatively high in these seven buildings; consumption ranged between 12-27 Btu/ft^2-DD compared to typical values of 12-15 Btu/ft^2-DD for the multifamily stock. Gas consumption decreased by more than 20 percent after the retrofit in six of the seven buildings. Except in one case, the retrofits had payback times of under eight years. The building with the lowest savings (7%) and highest payback (22 years) was the least energy-intensive prior to the retrofit.

G049.1 - G049.3: Switzerland - University Center for the Study of Energy Problems [23,24]

See description of retrofits O019 and O020.

G050: Chateau de Reze, Nancy, France - French Technical Center for Low-income Housing, CNET-HLM [25]

Building/Retrofit Description: This complex was retrofitted as part of the French ATH-1 program (see description for M018.1). This complex, built in 1961, consists of four large, uninsulated buildings (260 units) with high infiltration rates and a leaky, poorly balanced distribution system. Central gas boilers provided heat through radiant floor/ceiling slabs in each apartment, as well as domestic hot water. Apartments at the end of each distribution circuit had difficulty maintaining comfort conditions and obtaining sufficient hot water. The complex was extensively retrofitted, including exterior wall and roof insulation, ground floor insulation (over basements), improved distribution system valving, and installation of individual gas water heating units in each apartment. Retrofit costs, averaging over $2600/dwelling unit, were the highest of any ATH-1 site.

Data/Analysis: Monthly data, submetered separately for space and water heating circuits, are available for the pre-retrofit heating season, with weekly data (space heat only) for two seasons post-retrofit. CNET regressed energy use against outside temperature to estimate balance temperatures and heat-loss coefficients. Inside temperatures were monitored in nine apartments for one week, post-retrofit. Energy use in an adjacent, non-retrofitted site was monitored over the same years, for comparison.

Results: Space heat consumption decreased by 9% in the first year and 28% in the second year following the retrofit. However, an adjacent 10-building complex, with no reported retrofits, also saw a 21% reduction during the same period. In this second complex, both initial and final space heat energy intensities were about 1.4 times as high as the retrofitted complex. Without netting out savings from this second "reference" building, the simple payback at Chateau de Reze was 65 years—assuming that all costs relate to the space heat savings only (i.e., space heat energy use only used in calculating economic indicators).

The reported pre-retrofit water heating usage was extremely low, about 2.8 MBtu/unit-year, perhaps because of difficulties with the distribution system. Installation of individual water heating units may have increased consumption—along with the level of amenity for tenants. Living room temperature averages after retrofit were about 19-20°C, with bedroom averages varying from 15 to 21°C (59-70°F). Temperature fits showed a post-retrofit increase in the balance temperature of about 2°C.

OIL HEAT

O002: Trenton, NJ - Bumblebee Energy Systems/Trenton Housing Authority/HUD [26]

Building/Retrofit Description: Bumblebee Energy Systems received a HUD innovative energy conservation demonstration grant to install a temperature control system in Page Homes, an urban multifamily housing complex. Indoor temperature sensors were placed in one-third of the units, transmitting periodic readings to a microprocessor. Using this information, the computer adjusted the hot water temperature for the boiler. The hot water heat distribution system was also rebalanced and a separate gas-fired boiler was installed to meet domestic hot water requirements.

Data/Analysis: LBL normalized actual monthly fuel oil consumption by multiplying the estimated space heat fraction of total fuel oil consumption by the ratio of normal to actual year heating degree-days. LBL estimated annual operation and maintenance costs at $4000/year or $25/apt., based on Bumblebee System's service contract charges.

Results: Fuel savings in the complex were an impressive 44%. The pre-retrofit energy consumption was comparable to that found in other buildings operated by the housing authority yet it would be considered an 'energy guzzler' in comparison to the overall residential housing stock. The retrofit was very cost-effective with a payback time of less than one year. Eight other similar apartment complexes, used as a control group, showed almost 16% savings.

O003, O004, O005: Washington, DC, MD, & NY - Scallop Thermal Management [27]

Building/Retrofit Description: Scallop Thermal Management, Inc. is a private firm that agrees to supply heating, cooling and domestic hot water at a lower price than existing fuel bills. Except for a fuel cost adjustment, owners run no risk. Scallop provides fuel, service, operator training, and all operations and maintenance. The types of retrofit measures implemented in these three buildings included: replacement or altering of HVAC equipment, switching from pneumatic to electronic controls, distribution system improvements, re-lamping or other lighting load management, and cogeneration.

Data/Analysis: Annual fuel oil consumption and heating degree-days for one year before and two years after the retrofit were provided by Scallop. Scallop was unable to provide an estimate of fuel oil used to supply hot water. In weather-adjusting the consumption data, LBL assumed that 30% of the total oil consumed was used to heat hot water. Scallop estimated continual manpower requirements (operation & maintenance) at several hundred hours per year for each building, calculated at a rate of $30/hour. The annual operation and maintenance costs for the heating system improvements were large relative to the original investment.

Results: A 521-unit Washington, D.C. multifamily complex showed 6.7% savings. A 752-unit Maryland apartment complex attained only an average of two percent savings over two contract years. Finally, a 60-unit cooperative building in New York City achieved annual fuel savings of nine percent.

O008.1 - O008.4: New York, NY - NYC Housing Authority [28]

Building/Retrofit Description: In the winter of 1976-77, the NYC Housing Authority sponsored a demonstration study program to determine the energy savings resulting from installation of non-electric thermostatic modulating radiator valves (TRV) in steam-heated buildings controlled as a single zone. The measure was installed in multi-unit dwellings at four sites and changes in consumption were compared against four similar control buildings at the same sites.

Data/Analysis: Daily pre-and-post retrofit space heat energy consumption values were obtained from condensate meters at the eight buildings. A conversion factor of 980 Btu/lb (assuming low pressure steam at 10 psia, 240^{o}F minus saturated water at atm. pressure) was used and NYCHA's estimate of 70% boiler efficiency in calculating annual energy consumption.

Results: Significant reductions in energy usage occurred in seven of the eight buildings. However, causal attribution is difficult, because of such factors as the experiment's short time period (the pre and post retrofit consumption data were collected during the same heating season) and likelihood of 'independent' occupant retrofit measures and practices (i.e., apart from the study). Tenants did report increased levels of occupant comfort (more even distribution of heat in buildings). The study authors estimated energy savings of 6.8% specifically attributable to the TRV retrofit, obtained by calculating the percentage savings of the difference between three of the four study and control buildings weighted by the number of valves installed in each building. Energy savings (calculated as the difference between energy use in the study and control buildings) for the three successful buildings ranged from 2% to 12%. The authors ignored the anomalous results from the Ocean Hill site, because the control building had greater reduction in consumption than the study building.

O009.1 - O009.9: New York, NY - NYC Housing Authority [29]

Building/Retrofit Description: The New York City Housing Authority has an on-going program for replacement of steel casement windows with double-hung, double-glazed thermal break aluminum windows in order to save fuel and reduce maintenance costs. The original building windows were vulnerable to air infiltration, required substantial amounts of maintenance, and were frequently subject to glass breakage during windy weather.

Data/Analysis: One year of annual fuel oil consumption before and after retrofit was available for the nine housing projects. NYCHA subtracted energy used for hot water based on consumption during the summer months in order to calculate space heat savings.

Results: The window replacement retrofit achieved average space heat savings of about 17 percent with a 12-year simple payback time for the nine buildings. Energy savings at the nine buildings ranged from 9% to 22%. The building with the smallest number of dwelling units, Green Hill (733 units), had the lowest savings, while the largest building, Paterson (1791 units), achieved the highest space-heat energy savings. The Housing Authority also estimated that the retrofit reduced operation and maintenance costs by $30/dwelling unit or $30,000/year for a typical 1000-unit complex.

O013: Trenton, NJ - Trenton Housing Authority [30]

Building/Retrofit Description: Donnelly Homes is a 376-unit, family project built in 1939. Two-hundred twenty-two of the dwellings are apartments in three-story buildings, while the remaining 154 units are two-story duplex houses. In 1981, the antiquated existing Warren Webster heating controls (judged by an on-site consultant to be mainly inoperative) were replaced by a National Pumps and Controls system (NPC). The NPC varies the pressure of the steam in the heating system, depending upon the outside temperature, by regulating control valves in each zone's supply line. This system was also used at the Kerney, Campbell, and Wilson projects managed by the Trenton Housing Authority (see O014).

Data/Analysis: LBL used PRISM to analyze monthly oil (space heat and domestic hot water) and gas (cooking) utility bills for sixteen-month pre- and post-retrofit periods. In addition, LBL assumed that the annual cost of *properly* maintaining such a control system was roughly ten percent of the initial investment (based on conversations with the consultant retained by the Housing Authority). Because the old controls were not maintained, LBL assumed that annual O&M costs increased after the retrofit, estimated at 10% of the first-cost of the retrofit.

Results: Annual oil consumption decreased by 17% after installation of the heating controls.

O014.1 - O014.3: Trenton, NJ - Trenton Housing Authority [31]

Building/Retrofit Description: LBL analyzed changes in energy consumption that occurred at three Trenton Housing Authority projects (Kerney, Campbell, and Wilson Homes) after the original heating controls were replaced. The original heating system had steel fire-tube boilers and non-functional controls. The original boilers were replaced with H.B. Smith cast-iron sectional boilers (two at each project) with Preferred Utilities horizontal rotary burners, for providing steam heat. National Pumps and Controls systems, similar to the system that was installed at Donnelly (O013), replaced the original heating controls. The central boiler supplies both space heat and domestic hot water. Kerney and Campbell have tankless generators which use steam; Wilson's tankless generator uses boiler hot water. Buildings at these family projects are three stories, have flat roofs, and double-hung, single-glazed, aluminum frame windows.

Data/Analysis: Oil is used for space heat and domestic hot water; gas is the cooking fuel. One, two, and three years of monthly oil bills were collected at the Wilson, Kerney, and Campbell projects respectively. LBL assumed that annual O&M costs for the new heating control system were about ten percent of the initial investment. No additional maintenance costs were assumed for the new boiler.

Results: At Kerney project, the new heating control system created three heating zones for this five building project. Oil consumption after the combined boiler/control retrofit decreased by 29%. Average energy savings at Campbell project were 14%. Energy savings were much lower at the eight-building Wilson project compared to the other two projects (only 5.4%). The new heating control system enabled the eight buildings to be treated as four heating zones. During the installation period (the 1981-82 heating season), only one boiler was functional, and thus portions of the project received inadequate heat because the boiler was unable to meet the heating load. This condition led to a situation in which consumption during the installation period was lower (141-154 MBtu/unit) than either before (181 MBtu/unit) or after the retrofits were completed (172 MBtu/unit).

O015: Philadelphia, PA - Philadelphia Housing Authority [32]

Building/Retrofit Description: Southwark Plaza is a 886-unit, family and senior citizen complex built in 1963. The property includes a mix of three 25-story highrises and 27 two- and three-story row houses. Both types of buildings are heated from a single, central boiler room. Four boilers produce steam, which is then sent to remote equipment rooms, where it is converted to hot water for space heat and domestic hot water. In 1981, non-functional outdoor reset heating controls were replaced with new Honeywell outdoor reset controls (#W902A-1016 EU1).

Data/Analysis: No. 6 oil is burned in the boilers and gas is used for cooking. LBL used PRISM to analyze one year of monthly bills for both fuels before and after the retrofit.

Results: Following the retrofit, the combined NAC for both fuels decreased by 9.1% compared to pre-retrofit levels.

O016.1- O016.8: New York, NY - Miller and Miller [33]

Building/Retrofit Description: Eight high-rise buildings, owned by Miller and Miller Real Estate, were retrofitted between 1980 and 1983. The buildings range in size from 24 to 110 dwelling units; all use oil (#2 or #6) to provide steam heat and domestic hot water. The retrofits included new boilers and burners (essentially the same as the old equipment), double-pane windows, and "heat computers". The on-site computer checks the air temperature in selected apartments and regulates the boiler according to the indoor temperature readings. Six buildings received all four measures. Boilers, burners, and the computer were installed in one of the remaining structures; while boilers, burners, and windows were installed at the remaining building.

Data/Analysis: The building owner provided annual oil consumption data for these buildings. LBL then estimated the space heat fraction using typical end-use fractions for New York City and adjusted space heat consumption to a typical year using long-term annual heating degree-days. In addition, LBL estimated conditioned floor area from data on average room size and number of rooms per building.

Results: Oil savings ranged from 14% to 30%. Only two of the retrofits were cost-effective. One of these received the boiler, burner, and heat computer (not the costly window replacement); the other cost-effective measure produced the highest energy savings of any of the eight buildings. The owner did mention, however, that he was able to increase rents at all properties because of the new windows and boilers.

O017.1- O017.2: Philadelphia, PA - Community Energy Development Corp. [34]

Building/Retrofit Description: The Community Energy Development Corporation (CEDC) is a non-profit corporation that offers building owners technical and financial assistance in implementing energy conservation and passive solar strategies. These two buildings were retrofitted after an analysis by CEDC. In April 1984, these brick, low-rise structures received a number of energy conservation measures including clock thermostats, low-cost water-saving measures, and outdoor reset controls. In addition, R-30 attic insulation and storm windows were installed at O017.1 (746 S. Front St.), while at O017.2 (756 S. Front St.), a variety of heating system maintenance measures were carried out. About $2000/unit was invested at each building.

Data/Analysis: CEDC provided annual oil consumption for these buildings; oil is used only for space heating. LBL adjusted oil consumption to a typical year using the ratio of actual to long-term annual heating degree-days.

Results: After the retrofit, space heat energy consumption declined by 47% and 23%, respectively, at the two projects with payback times of five and 14 years.

O018: New York City, NY - NY Dept. of Housing Preservation and Development [35]

Building/Retrofit Description: Central Hudson Enterprises Corporation entered into a shared savings contract with the owners of Hugh Grant Gardens, a 139-unit Mitchell-Lama building in the Bronx. A $40,000 contract provided for a number of retrofits to the property's heating system: installation of an energy-efficient burner, sequence draft regulator, new time clocks on exhaust fans, Varivac steam controls, temperature limit controls, turbolators, and repair of steam traps. In addition, building personnel were trained in new maintenance practices for the heating equipment.

Data/Analysis: LBL used PRISM to analyze one year of pre- and post-retrofit oil delivery data collected by Central Hudson Enterprises.

Results: Energy savings of 26.5 MBtu/unit, or 19% of pre-retrofit consumption, were achieved at this building. Consumption declined despite the fact that heating controls were improperly set during four months of the heating season following the retrofit (December 1984 until March 1985). The heating system equipment and maintenance measures were cost-effective, with a payback time of about three years (including maintenance costs).

O019.1 - O019.70, O020.1 - O020.35: Switzerland - University Center for the Study of Energy Problems [23,24]

Building/Retrofit Description: The University Center for the Study of Energy Problems (CUEPE) at the University of Geneva has collected data on over 200 buildings, retrofitted with a variety of envelope and heating system measures. One hundred and four multifamily buildings were selected for inclusion in the LBL data base; almost all are oil-heated masonry structures, predominantly low-rise, ranging in size from three to 200 dwellings per building. The first group of 68 buildings (G049.1 and all O019s) were retrofitted between 1977 and 1983, with wall and ceiling insulation, boiler replacements and retrofits, heating controls, and window replacements. These measures were implemented as part of a national demonstration program. A second group of 36 buildings (G049.2, G049.3, and all O020s) were retrofitted under a private program from 1978 to 1985. Both shell and system measures were implemented in this group of buildings, but detailed descriptions of the types of measures were not available.

Data/Analysis: LBL was provided with annual raw energy use data for at least one year before and after each retrofit. Consumption data included energy used for either space heat only, or space heat and hot water. Multiple years of pre- or post-retrofit data were sometimes available; in these cases, consumption was averaged. Although no weather-correction was carried out on this data, changes in the number of heating degree-days between the pre- and post- retrofit periods were typically less than 10%, and always under 15%. CUEPE provided LBL with retrofit costs and energy prices, which were converted to dollars at 1981 exchange rates, and then escalated to dollars at the time of the retrofit. When a retrofit was carried out for both thermal improvement and building rehabilitation, the costs for the energy-conserving features only were given. No change in maintenance costs was assumed by CUEPE. In a few buildings, the space heating fuel changed as a result of the retrofit (typically from oil to oil and electricity or oil and gas). In these cases, the difference between pre-retrofit and post-retrofit energy costs (i.e., consumption times price during that period) was used in calculating cost-effectiveness indicators.

Results: Median pre-retrofit energy use was 70 MBtu/unit in the first group of buildings, and 64 MBtu/unit in the second. Typical energy savings were higher in the first group (18 MBtu/unit) than the second (11 MBtu/unit); however, median costs for the first group were $3900/unit, while for the second group, retrofit costs were much lower at $1640/unit (1987 $). Therefore, typical simple payback times were the same for both sets of buildings (22 - 24 years). Heating system measures were much less costly, and had much shorter payback times, than envelope retrofits within each group. For example, median heating system payback times for the first group of buildings was 10 years, compared to 29 years for shell retrofits. Within the second group, the difference was even more striking: 27 years for shell retrofits vs. 3 years for heating system measures.

O021: Marseille, France - French Technical Center for Low-income Housing (CNET-HLM) and French Energy Agency (AFME) [36]

Building/Retrofit Description: This retrofit project was one of a series conducted at five different public housing sites (2312 units) from 1977-80, under the French "TH-3000" demonstration program. This program, including a broad range of shell and heating system retrofits, was a successor to earlier retrofit operations emphasizing exterior shell insulation (TH-1000; 831 units) and interior shell insulation with limited system changes (TH-2000, 220 units). Across all the TH-3000 projects (also see data points O022, O023, O024, and M019), there was a roughly 10:1 range (per apartment unit) in the level of retrofit investment, energy savings, and cost-effectiveness. As might be expected, the lowest-cost measures typically involved operation and maintenance, followed by heating system improvements and then building shell retrofits.

This low-income housing retrofit site in Marseille included fifteen medium- and high-rise buildings, with a total of 1489 units. A variety of shell and distribution system retrofits were applied to twelve of the buildings (1221 units), with the remaining three serving as untreated control buildings (except for the effects of central boiler plant improvements). The conservation measures and monitoring were partly financed by AFME (French Agency for Energy Management). Following an initial effort in 1976 to improve operation and maintenance practices, the retrofit work began in May 1977, but was not finished until 1979. Retrofits did not occur at the same time in all the buildings, so it is very difficult to attribute the savings to one type of conservation measure. However, most of the work took place in two phases:

- Summer 1977: improvement of insulation (attic, basement floor, and/or outside walls, depending on the building) and remodeling of the heating plant (replacement of three of the four boilers, addition of a boiler economizer (fuel pre-heater) and a turbolator on two of the boilers, replacement of some circulation pumps and installation of sub-stations).
- Summer 1978: improvement of heating distribution lines and controls, and installation of radiators or resistance heaters in two of the buildings.

Before the retrofit, all the buildings were hydronically heated via radiant-floor systems, served by a central boiler plant. After retrofit, the heating system was modified in three of the buildings. One was controlled so the floors provided "base" level space heat up to 12° C, with the remaining 8°C being supplied by individual apartment radiators. Another building is heated only by radiators; the third building has both base level floor heating and electric resistance heaters.

Retrofit costs averaged $929/unit (1981$), or 3240 Fr/unit (1977 Fr), for the entire complex (including the three control buildings, with 268 units).† Retrofit costs were divided as follows: about 30% was for roof insulation, 30% for wall insulation, 10% for the boiler changes, distribution system and controls for 25%, with the remainder for miscellaneous shell retrofits. No costs were recorded for the O&M efforts which preceded the 1977 retrofits.

Data/Analysis: Seasonal energy use data are assumed to apply to space heat only; LBL had no documentation on domestic hot water usage. Heating-season consumption data (and corresponding degree-days) are available for the whole complex for 1975-76 (pre-O&M), 1976-77 (pre-retrofit), and 1977-78 (after the first-stage retrofits). Although data for the supplemental electric heaters was not available, these heaters were used very rarely, as the tenants did not wish to pay the extra cost. CNET-HLM normalized energy usage (using HDD ratios) to the typical season of 2880 HDD base 65°F (1600 HDD base 18°C). LBL based its primary analysis on a pre-post comparison for the entire complex, rather than a comparison of retrofit and control buildings, for three reasons: 1) questionable

† Costs are expressed in this fashion because energy data cover the entire complex. The average cost per *retrofitted* unit was $1135 (1981 $), or 3952 Fr (1977 Fr).

quality of the building-by-building data, 2) the inability to capture central boiler and distribution system savings using building-by-building comparisons, and 3) variance among the buildings, and the fact that retrofitted buildings, on average, used more energy than the controls.

Results: Weather-normalized space heat savings for the entire complex were about 32% including both retrofit stages. Space heat savings increased to about 37% if the initial O&M measures are considered. By itself, the first-stage retrofit (insulation and boiler changes) represented about three-fourths of the total cost and saved about 23%. The simple payback for both retrofit stages (excluding O&M) was under five years.

When the building-level data are compared for the winters of 1978 and 1979, the twelve retrofitted buildings saved, on average, 8.8% while the three control buildings averaged 6.8% savings (both figures exclude central system efficiency improvements). For individual buildings (if the measurements can be trusted), submetered savings range from 32% (in one of the buildings with individual TRV-controlled radiators added) to an *increase* of 15 %. In both seasons, the retrofitted buildings, as a group, used more space heat energy per unit than the control buildings. Short-term tests of boilers with and without the turbolator showed an efficiency improvement of about 1.4%. Comparisons of two boilers, with and without the economizer (fuel pre-heater), showed daily fuel savings of about three to four percent.

O022.1 - O022.4: Niort, France - French Technical Center for Low-income Housing (CNET-HLM) and French Energy Agency (AFME) [36]

Building/Retrofit Description: See O021 for description of the French "TH-3000" demonstration program. Of the nine low- and medium-rise buildings at this site, five were retrofitted and four served as paired reference buildings. However, heating distribution systems were re-balanced and ground floors (over the basement) insulated in all nine buildings.† All buildings were served by a central boiler plant, burning heavy (residual) oil. Retrofits for the four buildings included in the LBL data base were:

O022.1 - In this 24-unit building, the radiators were equipped with thermostatic valves in each room (4-5 valves per apartment, excluding only the bathrooms). Average retrofit costs were by far the lowest for any of the buildings at this site, equivalent to $209/apartment unit (1987$).

O022.2 - Retrofits to this 32-unit building included exterior wall insulation (45 mm of polyurethane foam), and insulation of the flat roof (20 mm of foam) at a cost of $3771/unit (1987$).

O022.3 - This 12-unit building also received exterior insulation (70 mm of rigid board on walls, 20 mm of foam on the roof) as well as caulking and an added glazing layer on the windows. Costs per unit were very high, at $10887/unit (1987$).

O022.4 - This building, with the same configuration as O022.3, had changes in the heating distribution controls (three-way valves) for apartments on the south side only. Costs were modest, at $650/unit (1987$). Some valves had mechanical problems, and were replaced in 1979.‡

Data/Analysis: Energy data are based on calorimeters installed at each building.§ Weekly readings of energy use and average outside temperature were taken for 10-24 weeks during the 1978-79 heating season; no inside temperatures were monitored. CNET-HLM estimated a heat-loss coefficient and balance temperature for each building based on a regression of the weekly calorimeter and average outside temperature data. These parameters, along with heating degree-days during a normal heating season (2182 HDD base 18° C or 3928 HDD base 65°F), were used to calculate energy consumption in a typical year.• Since there is no pre-retrofit energy use data, savings are based on a comparison of each retrofitted building with its paired reference building (same size and configuration). In two cases, LBL adjusted energy use of the reference building because the floor area of the reference building differed by a few percent from that of the retrofitted building.

† Costs and savings from these retrofits are not included in the LBL analysis.

‡ The fifth building was excluded due to lack of a suitable comparison building.

§ LBL's analysis assumes that the building-level energy data include space heating only.

• We also compared these regression-based estimates of heating energy for an average season with a simple scaling by degree-days, to base 18° C and to each building's own balance temperature. All three results agreed within about 5 %.

Results: Space heat savings were 9-11% for three of the buildings (based on the post-retrofit comparisons of retrofitted and reference buildings), with the exception of the highest-cost building, with exterior insulation and double-glazing, which saved 25% compared to its reference building. However, the very high cost of insulation retrofits resulted in unacceptably long paybacks (eighty years) at O022.2 and O022.3. Only the projects involving heating control retrofits had payback times of ten years or less.

O023.1 - O023.4: Voiron, France - French Technical Center for Low-income Housing (CNET-HLM) and French Energy Agency (AFME) [36]

Building/Retrofit Description: See O021 for description of the French "TH-3000" public housing demonstration program. This site consists of four buildings retrofitted in 1977, and a fifth (unchanged) reference building. Each building has five floors and between 21 and 23 units. Different techniques were used on each retrofitted building:

- O023.1: distribution circuits were changed to separately control each facade of the building in response to solar gains. The cost was $552/unit (1987 $), including the building submeter installed for monitoring purposes (which represented about $165/unit of the total cost).
- O023.2: a second glazing layer and caulking was installed on the windows, plus thermostatic radiator valves (TRVs) and a "heating-cost meter" installed at each radiator. These meters are not used for billing purposes, but rather only to provide the occupants with information about their consumption. Retrofit costs were $1519/unit (1987 $), higher than for the other buildings at this site. Of this, the double-glazing and caulking accounted for about 80%, while the tenant utility meter cost about $165/unit.
- O023.3: only "heating-cost meters" were installed, at a total cost of about $213/unit (1987 $). About 80% of this cost was for the building submeter; the heating-cost meters were only about $8-11 each, installed.
- O023.4: heating-cost meters and thermostatic radiator valves were installed on all radiators, at a cost (including the building submeter) of about $411/unit (1987 $).

Data/Analysis: See description of O022 for discussion of CNET analysis method (e.g., use of paired reference buildings to determine savings). Submetered energy data for each building and outside temperatures are available for one- to four-week periods, from 6 October 1978 to 4 April 1979. Monitored inside temperatures are available for five to ten units in each building, for two weeks in February 1979. Weather-corrected energy usage is calculated from the heat-loss coefficient and balance temperature, for a typical heating season (2499 HDD base 18°C, or 4498 HDD base 65°F). The weather-correction is based on the average season's degree-days to each building's balance temperature, rather than to base 18°C. Energy use estimates assume an efficiency of 0.7 for the central boiler plant and distribution system.†

Results: Space heat savings ranged from three to about thirty percent in the four buildings. Simple payback times are under six years for three of the four buildings (even when the cost of the submeter is included), but eighty years for the double-glazed building (O023.2). In building O023.2, shell heat losses (based on the regression heat-loss coefficient) were reduced about 9% by double-glazing and caulking, but the estimated balance temperature was higher than for the reference building, due to higher inside temperatures (averaging 20.9°C vs. 19.8°C) and no re-balancing of the distribution system to account for reduced shell losses. As a result, net savings in heating energy were only three percent; combined with very high retrofit costs, the payback period is several decades. Energy consumption decreased by 19% in building O023.4, giving a four year payback time. Compared with building O023.2 (which received similar retrofits along with double glazing), savings were greater, costs much lower, and inside temperatures lower (17.5-20.5°C, vs. 20-22°C). Authors of the monitoring report suggested that the better results in this building were due, in part, to use of the same contractor to both install and maintain the TRV's and heating-cost meters.

† LBL also compared these regression-based estimates with a simple scaling by heating degree-days (using degree-days to both base 18°C and to each building's balance-temperature). The three sets of normalized results, in percentage energy savings, differed by less than two percentage points.

O024.1 - O024.2: Grenoble, FRANCE - French Technical Center for Low-income Housing (CNET-HLM) and French Energy Agency (AFME) [36]

Building/Retrofit Description: See O021 for description of the French "TH-3000" demonstration program. Shell retrofits were performed in 1977-78 on two buildings heated by an oil-fired central heating plant: one high-rise building (11 floors, 45 units) and one low-rise building (4 floors, 24 units). Both buildings received wall, roof, and ground floor (over basement) insulation; the high-rise was also fitted with double-glazing (previously installed on the low-rise). Exterior wall insulation was used on the high-rise, while foam insulation was injected in an existing wall cavity on the low-rise (at about one-tenth the cost per m^2). Average cost of the shell retrofits was extremely high for the larger building, at $7125/unit (1987 $). This investment represented more than ten years of energy costs (based on pre-retrofit usage). Average retrofit cost for the low-rise was $1128/unit (1987 $), about two years of energy costs.

Heating distribution circuits were balanced in both retrofitted and reference buildings. Prior to the retrofit, secondary distribution stations (one per building) were added to the existing high-pressure distribution stations. This may have allowed better building-by-building control, but there are no system-level consumption data to confirm this.

Data/Analysis: See description of O022 for discussion of CNET analysis method (e.g., use of paired reference buildings to determine savings). Energy consumption and average outside temperature were measured every one to four weeks by a submeter at each building, for virtually the entire heating season (2 October 1978 to 14 May 1979). We use these raw numbers, for retrofitted and reference buildings to represent a typical season (actual HDD for this period were 2503 base 18°C, or 4505 base 65/(deF). Central heating system efficiency was assumed to be 70%. There are no measured inside temperatures.

Results: Heating consumption data for the 1978-79 season show a 57% savings on the high-rise, due to a 40% reduction in the heat-loss coefficient, and a reduction in the balance temperature from 20°C to 16°C (both compared with the reference building). The 20°C, combined with an estimated 3° of free heat, indicates overheating in the reference building. Savings in the low-rise were about 20%. Actual savings in both buildings were less than predicted prior to retrofit (78% and 74%, respectively); the greater discrepancy for the low-rise building is presumed to be due to poor quality control in injecting the foam wall insulation. Payback time for the low-rise building was ten years, while retrofits to the high-rise building had a payback time of 20 years.

MIXED HEAT

Retrofit projects were classified as "mixed heat" for one of the following reasons: 1) buildings used more than one space heat fuel (e.g., gas and oil with typically one fuel being the primary space heat fuel and the other serves as a backup), or 2) the space heat fuel changed as part of or at the same time as the retrofit.

M014.1 - M014.7: Sweden - Royal Institute of Building Technology [37,38]

Building/Retrofit Description: The Swedish government sponsored an extensive program of home loans and grants for the installation of various conservation measures in existing residential buildings. The Royal Institute of Technology (RIT) performed an in-depth analysis of several hundred single- and multifamily houses. Buildings included in the final analysis met the following criteria: no other conservation measures were performed by the residents, no other structural changes to the building, and multi-unit buildings had five or more apartments. Sample buildings 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. Attic insulation, wall insulation, and heating controls were installed in the multifamily buildings.

Data/Analysis: The RIT analyzed fuel bills for a period of at least one year before and after the retrofit for each building, 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 five counties) by measure or combination of measures. In calculating average values for heated dwelling area, energy consumption, and predicted theoretical savings, LBL weighted the above values by the number of buildings from each region to estimate the mean. 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.

Results: Average savings from these retrofits was 9% of space heat and domestic hot water consumption.

M015: St. Paul, MN - St. Paul Housing Authority [39]

Building/Retrofit Description: St. Paul Housing Authority received a HUD innovative energy conservation grant to install a computerized energy management system in three high-rise properties inhabited by elderly tenants. Many existing controls were tied into the computer. The system's main functions included issuing preventive maintenance orders, reducing electrical demand charges by minimizing peak usage, malfunction alarms, and lighting and temperature control in public areas. Prior to this retrofit, the Housing Authority had a rather extensive conservation program in operation and had undertaken many low cost/no cost retrofits (showerflow restrictors, reduced hot water temp. to 120^{o}F, insulated pipe ducts, etc.) plus various retrofits designed to improve heating system efficiencies (e.g., new burners on boilers). The system went into operation during the 1980-81 heating season.

Data/Analysis: LBL compared fuel consumption from the 1978-79 heating season (before) to 1981-82 usage, normalizing the raw consumption and heating degree-day data to the long-term average value. According to the Housing Authority, the system also provided annual electricity savings of 404,000 kWh in all three buildings. To account for this effect, LBL converted the electricity savings to fuel-equivalent units, which were then added to the pre-retrofit usage (thus increasing the overall savings).

Results: The electricity savings substantially reduced the simple payback time for the investment to roughly four years.

M016: Trenton, NJ - Trenton Housing Authority [40]

Building/Retrofit Description: Two retrofits were implemented at the Haverstick project managed by the Trenton Housing Authority. The project was built in 1955 and consists of two-story walk-up apartments. The original boiler supplies DHW, while space heat is supplied by Preferred Utilities horizontal rotary boilers that were installed in the late 1970s. Heating control is provided by a Sarcotherm outdoor-reset hydrostatic three-way mixing valve, although the controls do not appear to function correctly. In the first retrofit, casement windows were replaced in the summer of 1983 by double-hung aluminum frames with a single glazing layer. In the second retrofit, the space heat boilers and domestic-hot-water generators were replaced with 32 high-efficiency, Hydropulse condensing pulse-combustion boilers in October 1984. Each boiler has an input rating of 150 kBtu/hour; the total capacity of the system was approximately 5000 kBtu/hour. Eight of the modular boilers supply domestic hot water to a 500-gallon storage tank.†

Data/Analysis: Prior to the retrofit, space heat and domestic hot water were provided by oil, while natural gas was used for cooking. LBL considered both fuels in the analysis. After the boiler retrofit, all of these end uses were supplied by natural gas. One year of monthly data was collected both prior to and between the two retrofits. Six months of weekly readings were available after the heating system replacement. The total cost of the boiler replacement was $1776/unit (1985 $). The *incremental* cost of the high-efficiency boilers above the cost of ordinary boilers was estimated at $547/unit, based on actual bids the housing authority received for the two alternative heating systems.

Results: Energy usage after the window retrofit did not change significantly. This suggests that the occupants were probably opening their new windows to maintain a comfortable indoor temperature. This is not too surprising because window-opening may be the only control option available to residents if heating system controls are not working properly. Consumption decreased by about 50% in the six months following the boiler replacement. Using the incremental cost of the high-efficiency boiler, this retrofit was very cost-effective, with a payback time of about one year.

M017.1 - M017.3: New York, NY - Rothschild Associates [41]

Building/Retrofit Description: The owner of several small New York City high-rise buildings has carried out an extensive energy management program that has involved installation of a series of conservation retrofits during the past seven years. Consumption has been reduced by as much as 50% during this period. Installed measures include new boilers and burners (e.g., Rockmills Scotch-Marine boilers with Iron Fireman air-atomizing burners, replacing

† The boilers tend to be very noisy. The noise is not bothersome at Haverstick, where the heating plant is located in a separate building, but it might cause problems in buildings with heating plants that are located near living quarters.

converted coal boilers with rotary cup burners), auxiliary domestic hot water generators, thermal windows, attic insulation, computerized energy management systems (consisting of on-site computer with outdoor sensor, burner operation sensor, and sensors in 10% of the apartment units), and pipe insulation.

Data/Analysis: The owner provided LBL with six years of annual gas and oil consumption data for the three buildings. Using this data and information on the date of each retrofit, LBL defined appropriate before and after periods for each retrofit. LBL estimated baseload usage from summer utility bills and then adjusted the space heat fraction by the ratio of normal to actual year heating degree-days.

Results: The savings due to single measures cannot be isolated, because most of the retrofits were carried out in groups. However, the highest savings (16-38%) were achieved in buildings that received new boilers, burners, and attic insulation, while expensive window retrofits (approximately $1000/unit) did not produce significant changes in consumption. Payback times for retrofit combinations that did not include window replacements were less than five years.

M018.1: Moulins, France - French Technical Center for Low-income Housing, CNET-HLM [25]

Building/Retrofit Description: This is one of a series of French multifamily retrofit demonstrations, monitored by CNET-HLM, the French Technical Center for Low-income Housing (public housing) under the ATH-1 program, 1979-81. The ATH-1 program tested different combinations of shell and system measures at each site. This seven-building complex (four five-story buildings and three 11-story towers) was constructed during the early 1960s, with no insulation. The space heating system was substantially changed during 1978-79. The original oil-fired boilers were replaced with three gas-fired condensing boilers, intended to provide hot water and low-temperature "base" space heating (to maintain inside temperatures at about 15°C). Electric resistance units were installed in each apartment to provide supplemental space heat, billed to each tenant. The flat roofs of each building were insulated at the same time. Retrofit investments, at about $1500/dwelling unit, were twice the average for all ATH-1 sites.

Data/Analysis: Typically, data available for the ATH-1 sites include post-retrofit (and at some sites, pre-retrofit) heating fuel use and outside temperatures, monitored on a weekly or bi-weekly basis. For this particular complex, heating season data are available for the central heating system of the complex for one year before retrofit, the year during retrofit, and two post-retrofit years. CNET-HLM adjusted reported energy use by scaling actual degree-days (pre- and post-retrofit) to 4500 HDD (base 65 °F; or 2500 HDD, base 18°C). The seven buildings were separately metered for the two post-retrofit years only; during this period, consumption readings were taken every 2-3 weeks, to calculate a building energy signature (regression against outside temperature). Consumption by the electric supplemental heaters was submetered in 30 apartments, for parts of the season during retrofit and the two post-retrofit seasons.

Results: Tenants, unwilling to use and pay for their own supplemental heating, complained about inadequate central heat when the new system was first installed. In response, building managers increased the heat output from the central plant so that apartment temperatures were kept at about 20°C (68°F). This additional central heating, plus the fact that shell retrofits were completed during the '78-'79 heating season, resulted in only 27% space heat energy savings that year. The level of central heating was gradually lowered during the following season ('79-80), with savings for the next two full post-retrofit seasons averaging 55%. However, for the 30 apartments with the electric heating units submetered, about two-thirds still did not use appreciable amounts of supplemental electric heat after two years. Tenants apparently preferred to keep their bills low, and accept reduced comfort levels provided by the "base" heating alone. Metering for individual buildings during 1979-80 showed per-unit variation among buildings of about 35% (including both space and water heating). Despite the high energy savings, the payback time of this project exceeded 30 years.

M018.2: Le Ranzai, France - French Technical Center for Low-income Housing, CNET-HLM [25]

Building/Retrofit Description: See M018.1 for description of the French ATH-1 program. This 304-unit complex includes 20 small apartment buildings and eight single-family units, all served by a central plant. Retrofits in summer 1978 included exterior roof insulation, reduction of large infiltration losses through plumbing access areas, and improved distribution controls to reduce overheating of some buildings. One year later, in March 1979, the boiler was converted from oil to gas. Retrofit costs, averaging about $250/unit, were by far the lowest of any ATH-1 site.

Data/Analysis: There are three years of pre-retrofit data, available only for the full heating season, plus weekly data for two post-retrofit heating seasons. These data include both space and water heating (no submetering) and do not include summer hot water (or boiler standby) use. Inside temperatures were monitored in selected apartments (not clear whether this was before or after the distribution system control changes). Based on the strip chart records, LBL estimated that differences among apartments within a building were typically 2°C (up to a maximum of 5 °C in one building); differences in the averages *among* buildings were up to 3 °C.

Results: During the first season after shell and distribution control retrofits, space plus water heating energy declined about 25 %. Near the end of this heating season, the boilers were being converted from oil to gas, which may have affected consumption. (This season is not included in the LBL analysis.) For the following two seasons, space and hot water energy declined by over 50% from the pre-retrofit level (average of the two seasons). Prior to retrofit, energy usage at this site was about 50% higher than average for the other ATH-1 retrofit projects. Floor area per apartment was also larger, but only about 15%. The payback period, under one year, was far shorter than for other ATH-1 sites.

Energy use values were weather-adjusted to a typical French heating season. However, since this scaling was done for the *total* usage (space plus water heating), this tends to over-correct for weather by the fraction representing water heating energy (based on other sites, we assume that hot water energy is, at most, 20 % of the total). In this instance, the post-retrofit seasons averaged about 10% fewer HDD (1928 HDD base 18°C) than the pre-retrofit seasons (2141 HDD base 18°C), and both pre- and post-retrofit data were normalized upward to the assumed national average of 2500 HDD base 18°C. Thus, including water heating usage in the weather-adjustment tends to make the adjusted savings conservative by about 5%, compared with weather-adjusting the space heat energy alone. On the other hand, data cover the heating season only, not including summer boiler use for hot water and standby. If this summer usage were included, it might add another few percent to the reported consumption, but also reduce the estimated percent savings. Given all these factors, the percentage savings, rather than the absolute level of energy savings, is probably the best indicator for comparison with other projects.

M018.3: Le Haut du Lievre, Nancy, France - French Technical Center for Low-income Housing, CNET-HLM [25]

Building/Retrofit Description: See M018.1 for description of the French ATH-1 program. This large complex, with 2912 units in 15 buildings (two high-rise, 16 and 18 stories; the rest 5-story), was built around 1960. Ten of the buildings were served by a central, coal-fired heating plant. All the buildings were originally uninsulated. Retrofits installed between August 1978 and April 1980 included system and shell measures, varying by building. Five buildings were switched from separate gas or oil heat to the central (coal) plant; four of these were also retrofitted with double-glazing and ground-floor insulation. Retrofits in the remaining 10 buildings included ground floor and roof/gable insulation, and (in one high-rise building with 786 units) reduced mechanical ventilation in the kitchens. On average, retrofits were fairly inexpensive (about $370/unit), less than half the average for all ATH-1 sites.

Data/Analysis: Metering (for space heat and water heat separately) covered three groups of buildings: a single gas-heated building, a group of four oil-heated buildings (all five of these were converted to the central coal plant as part of the retrofit program), and the remaining 10 buildings served by the central plant. Periodic usage and outside temperature measurements were sporadic at this site, providing only about 5 points per season with which to estimate a regression.

Results: Overall energy savings were a modest six percent, and the payback time was over 25 years. This was due in part to increased consumption in the four (formerly oil-heated) buildings. The monitoring team speculated that this increase was due to improved comfort levels (i.e., under-heating prior to the retrofit and conversion to the central system).

M018.4: La Rose le Clos, France - French Technical Center for Low-income Housing, CNET-HLM [25]

Building/Retrofit Description: See M018.1 for description of the French ATH-1 program. This project consisted of 734 units in 12 buildings, mostly four-story plus two 10-story towers. Retrofits involved building shells and central heating systems: burner replacement to convert the central plant from oil to gas, exhaust stack heat recovery economizers, ground floor and roof insulation, caulking and weatherstripping, and balancing and improved control of the distribution system (both among buildings and by facade, within buildings). Investments (about $1200/unit) were in the mid-range for the ATH-1 projects.

Data/Analysis: Consumption and degree-day data for the central heating system are available for one to two-week periods, for the post-retrofit season only; prior to retrofit, seven years of system-level data are available, but only for the entire heating season.† Electricity use for pumps by the central plant and each distribution station was also recorded for four-month periods, before and after retrofit. No inside temperature measurements were reported.

Results: Weather-adjusted savings were about 15%. During the same time, electricity requirements for pumping more than doubled, due to installation of larger substation pumps and more complex control circuits. Even at this higher level, electricity for pumps represented only about 2% of the heating system total energy use. Because this retrofit was fairly expensive, the payback time was 45 years.

M019: Voiron, France - French Technical Center for Low-income Housing (CNET-HLM) and French Energy Agency (AFME) [36]

Building/Retrofit Description: See O021 for description of the French "TH-3000" demonstration program. There were two identical high-rise (10 story, 40 unit) buildings at this site, served by a central, oil-fired boiler plant. One building was retrofitted while the other served as an untreated reference building. The retrofits included 6 cm. of exterior wall insulation, double-glazing and caulking of windows, and addition of individual thermostatically controlled, electric room heaters, to supplement central heat (supplied at a reduced temperature). Cost of all retrofits was fairly high, averaging $3719/apt. unit (1987 $). Wall insulation represented 30% of this; double-glazing 40%, and the electric heaters (plus submetering in selected apartments, for monitoring and billing purposes) the remainder. In all, 210 heaters were installed (about five per apartment) at a cost of $173 each.

Data/Analysis: See description of O022 for discussion of CNET-HLM analysis method (e.g., use of paired reference buildings to determine savings, regression technique). Energy data are based on calorimeters installed at each building. Weekly readings of energy use and average outside temperature were taken during the 1977-78 and 1978-79 heating seasons, but instrument problems precluded use of the second season of data. Our analysis assumes that the building-level energy data include space heating only. Electric ("supplemental") heat circuits were submetered in twenty of the forty apartments in the retrofitted building, for the 1978-79 season only. CNET-HLM scaled the aggregate results to represent the whole building, and adjusted to 1977-78 weather conditions. Inside temperatures were monitored in twenty apartments (11 in the retrofitted building, 9 in the reference building) for one week, in February 1979. The regression-estimated balance temperature was 16 °C in the reference building, and 13.5 °C in the retrofitted building (including the contribution of about 1 °C from electric heat). Individual tenants' use of electric heat varied widely. Although electric heating use per apartment averaged 867 kWh for the season, seven of the twenty monitored units used essentially no electric heat in 1978-79, while another four used less than 250 kWh.

Results: Raw savings (based on post-retrofit comparison of the retrofitted and reference buildings) were 41% for the central heating energy only; or about 32% considering the electric heat requirements. After normalizing these data to a typical year (4498 HDD base 65°F, or 2499 HDD base 18°C) using each building's balance temperature and heat-loss rate, the fuel-only savings were about 51%, or 45% after including energy for electric heat, but *not* allowing for the differences in average inside temperatures (see below). Consumption was therefore 59.7 MBtu/unit for the reference building and 32.9 MBtu/unit for the retrofitted building.† At local fuel prices (including taxes), this translates to a simple payback of fifteen years.

ELECTRIC HEAT

E012: New York, NY - New York City Housing Authority [42,43]

Building/Retrofit Description: The New York City Housing Authority replaced incandescent hall and stairwell lights with 20-watt fluorescent fixtures in 13 buildings. This retrofit cost about $50 per fixture, based on a review of the installation contracts. Electricity billing data were obtained from one housing project (830 Amsterdam).

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† End-uses are not clearly specified, but apparently include both space and water heating.

† Of note, a simple scaling of these part-season results to a "typical" season, using base 18°C degree-days, yields estimated consumption that is 10% higher for the retrofitted building, and 6% lower for the reference building, thus reducing net (fuel plus electricity) savings to 35%.)

Data/Analysis: The longer lifetime of the fluorescent bulbs led us to estimate an annual reduction in operation and maintenance costs of $5/apartment.

Results: Electricity used for lighting decreased by 62 percent after the retrofit. This retrofit was extremely cost-effective with a payback time of 1.4 years.

E019.1 - E019.3: Seattle, WA - Seattle City Light and Seattle City Council [44]

Building/Retrofit Description: In 1981, the Seattle City Council authorized Seattle City Light (SCL) to fund a pilot weatherization program for apartment buildings with low-income tenants. Three low-rise, electrically heated buildings were selected to receive weatherization measures during the 1981-82 heating season. Each building has between 17 and 21 dwelling units. The retrofits included crawl-space insulation, pipe and water-heater wraps, vapor barriers, insulated windows, and water-heater temperature setback. The total cost of the retrofits at the three buildings was $55,000, 75% of which was was spent on insulated windows. Building A (E019.1) had higher occupant density (2.0 persons/unit) than either building B (E019.2, 1.4 persons/unit) or building C (E019.3, 1.5 persons/unit).

Data/Analysis: LBL used PRISM to analyze bi-monthly electric bills during a four-year period (one year before the retrofit and three years after). Interestingly, energy use at each building continued to decline by two to three percent in the second and third year after retrofit. SCL is unsure of what might account for the additional decline in energy use, although occupants might have been responding to rapidly increasing electricity prices.

Results: Significant electricity savings were achieved (7%, 24%, and 16% at E019.1, E019.2, and E019.3), although high retrofit costs ($500 to $1200/unit) and inexpensive electricity rates ($0.038/kWh) made the weatherization measures only marginally cost-effective. Simple payback times at each building were in excess of 15 years, and the net present value was negative in each case.

E021: New York City, NY - New York City Housing & Preservation Dept., BNL, and NYSERDA [45,46]

Building/Retrofit Description: An innovative energy management system (EMS) was installed in two 40-story apartment complexes, called Manhattan Plaza, located in the Times Square neighborhood of New York City. The buildings were constructed in 1976 and included some commercial office space along with approximately 1660 apartment units. Each apartment unit utilized individual cooling and electric resistance heating units. The EMS selected was a carrier wave (power line subcarrier) type which utilizes the existing electrical wiring network within each building to transmit control signals from a central station to electrical loads (heating/air conditioning units) located in the apartments. The EMS turned the individual heating/cooling units on and off (with override by tenants) on a schedule determined by the building operator. The initial cost of the EMS was approximately $600,000 or $360/unit. This demonstration project confronted numerous difficulties during the course of the study, including intermittent component failures, programming and operational errors, and data acquisition problems.

Data/Analysis: Hirschfeld calculated energy savings by comparing total apartment energy use during the "controlled" and "uncontrolled" periods over a three year period, using heating degree-days to adjust for weather differences.

Results: Electricity savings were 1400 kWh/unit, a 14 percent decrease from the uncontrolled usage level. The authors stress the fact that complex EMS systems need strong field service capability and that technical support requirements were significantly underestimated. In addition, they note that tenant behavioral patterns were a particularly significant factor in this program.

E022: New York City, NY - Mutual Redevelopment Housing [47]

Building/Retrofit Description: Penn South Cooperative is a group of 15 buildings, containing 2820 units, that is managed by Mutual Redevelopment Housing. In 1980, Penn South became the first cooperative in New York State to utilize submetering of electricity following the New York Public Service Commission 1976 decision to allow submetering in cooperatives and condominiums. The conversion from master metering was facilitated by existing wiring for individual metering that had been installed when the buildings were constructed. Therefore, only individual meters had to be installed, at the relatively low cost of $95/unit (1985 $).

Data/Analysis: Before the metering switch, each tenant was charged a fixed percentage (based on apartment size) of the building's electricity bill.

Results: After the conversion, electricity bills for 73% of the residents decreased compared to charges incurred under the master-metered system. Based on first-year energy savings, the metering conversion was cost-effective, with a simple payback time of less than two years.

E025: Newark, DE - State of Delaware Div. of Facilities Management [48]

Building/Retrofit Description: The Department of Energy funded the State of Delaware to test the "house doctor" approach on a four-unit senior apartment building in Newark, DE. The building, located in Marydale Retirement Village, was of recent construction (1980), and had a concrete slab-on-grade foundation, R-11 to R-19 in the interior wall cavities, double-hung windows with two panes, and electric resistance baseboard heating units with thermostats in each room. In this retrofit, a blower door and an infrared camera were used by a "house doctor" to identify and seal areas of heat loss (e.g., attics and basement, convective loops within wall cavities). Gaps in the attic floor were caulked and attic hatches insulated and weatherstripped; caulking and weatherstripping were also installed around the exterior wall and concrete slab joint, window frames, and door jambs. In addition, water heater temperatures were reduced. Blower door tests before and after house-doctoring indicated that the reduction in the number of air changes per hour ranged between 33-44 percent in the four units.

Data/Analysis: LBL used PRISM to analyze three years of electric utility bills that were available for each apartment (including two years of post-retrofit data). Results presented in the data base are the average from three apartments only, because LBL excluded one apartment in which the original occupant moved.

Results: First-year savings ranged from 6.3% to 28.1% of pre-retrofit consumption. Energy use in the second year following the retrofit increased to 7.1% above pre-retrofit consumption in one apartment; of the remaining apartments, one show increased savings and the other slightly decreased savings, as compared to first-year consumption. Average savings over both post-retrofit years and all three apartments was 11 percent. The simple payback time for the group of three apartments is 2.1 years (assuming no maintenance costs, and a ten-year lifetime). The author of the report states that the $250/apartment charged by the house doctor is somewhat below market rates, and that $300/apartment would be a fairer assessment of actual costs that one would encounter for house doctoring; however, the increased cost has minimal impact on the economics of this retrofit (i.e., payback time of 2.5 years).

E026.1 - E026.3: New York City, NY - NYSERDA [49]

Building/Retrofit Description: New York State Energy Research and Development Authority (NYSERDA) sponsored a project that assessed the impact of electric submetering technologies in four large multifamily buildings located in New York City. None of the buildings heat with electricity and a sizeable fraction of the units have window air conditioning units. E026.1 (Woodlawn) is a nine-story building with 100 units and 79 air conditioners. E026.2 (Bell Park Gardens) is a low-rise, 800-unit complex which has 39 two-story buildings and includes about 1700 air conditioning units. E026.3 (Strycker's Bay) is a 234-unit project which includes two high-rise buildings (21 and 17 stories high) and has approximately 350 air conditioners. These three buildings are all tenant cooperatives. Submetering allows individual apartment dwellers to take advantage of electricity purchased at bulk discount rate, with each apartment charged on the basis of electricity consumed. Three types of submetering systems were implemented at these sites. An electronic system that used dedicated low-voltage wiring for communication was installed at Woodlawn. Electromechanical meters were installed at Bell Park Gardens, while a hybrid system, which typically uses electromechanical meters that are interfaced with electronic communication equipment, was used at Strycker's Bay. The cost of the submetering systems varied from $200/unit for the electromechanical meters to $425/unit for the electronic and hybrid systems.

Data/Analysis:

The study authors normalized electricity consumption to account for the effects of common area usage and weather (cooling degree-days). The result of their analysis was an estimate of apartment-only electricity consumption in a year with typical weather before and after installation of the submetering system. LBL excluded the fourth building site, Morris Heights, from the data base because it had only five months of electricity consumption data after system installation. In the economic analysis, LBL also included annual service charges for meter reading and billing service of about $20/unit.

Results: Electricity consumption decreased between 17-20 percent of pre-retrofit levels in these three projects, presumable because of changes in tenant behavior. Payback times ranged between three and nine years (including the cost for meter reading and billing service).

E027.1 - E027.24: Hood River, OR - Oak Ridge National Lab [50-53]

Building/Retrofit Description: The Hood River Conservation Project was intended to test the upper limits of a residential retrofit program. It was funded by the Bonneville Power Administration and operated by Pacific Power & Light Company in Hood River, Oregon. This three-year, $21 million research and demonstration project installed as many cost-effective retrofit measures in as many electrically-heated homes in Hood River as feasible (based on an audit). Single-family, multifamily, and mobile homes were retrofitted, totalling 2988 all-electric dwellings. Five main categories of measures were installed: insulation of ceiling, walls, floor, and heating ducts; storm windows and sliding glass doors; infiltration control, including caulking, window weatherstripping, door weatherstripping, and electrical outlet gaskets; water heater wraps, pipe wraps, and low-flow showerheads; and miscellaneous items such as clock thermostats and air-to-air heat exchangers.

LBL aggregated individually-metered data from apartments in multifamily buildings of at least four units to the building level to incorporate these retrofits in the BECA-B data base. The typical multifamily building in Hood River has about 6-7 units/building, is one to two stories, has wood-frame construction with metal frame windows, and is less than 20 years old. Apartments tend to be small, about 780 ft^2/unit, with an average of 1.8 occupants/unit. Prior to retrofit, the typical insulation levels were R-14 in the attic, R-11 in the walls, and R-0 under the floor, while glazing levels were split about equally between single and double pane windows (i.e., 55% single; 45% double). After retrofit, target levels were achieved in most multifamily buildings for attic insulation (71% of units received R-49), floor insulation (80% of the units received R-38 in the crawl space/basement, while 61% got R-10 perimeter insulation for slab-on-grade floors), and windows (over 95% of the units got triple glazed windows). However, structural barriers precluded installation of R-19 insulation in walls in most cases. Retrofit costs were high, over $1800/unit, with window and sliding glass door retrofits accounting for about 50% of that total.

Data/Analysis: LBL included individual unit PRISM runs done by ORNL for four years (pre-retrofit 1982/83, 1983/84; during retrofit 1984/85; post-retrofit 1985/86) that met the SOMEFIT criteria (i.e, no master-metered buildings, each analysis period has at least four periods and 270 days). This produced a final sample of 340 units at 24 building sites. In addition, LBL defined pre- and post-retrofit periods for each individual building based on the date of the retrofit.† In our economic analysis, the lifetime of retrofits varied between 13 and 20 years among buildings, based on LBL's literature review of reported lifetimes for similar measures. This is much lower than the 35-year lifetime used by ORNL.

Results: Decreases in NAC ranged from -2 to 31% of pre-retrofit consumption, with average savings of 14% (weighted by number of units/building). The retrofits were expensive, ranging from $340 to $3300 per apartment (1985 $). Most measures, however, were paid for by the project and not the building owners or occupants. Simple payback times were at least fifteen years for all the buildings.

E028.1 - E028.15: Seattle, WA - Seattle City Light [54-56]

Building/Retrofit Description:

In mid-1985, Seattle City Light (SCL) retrofitted fifteen multifamily buildings as part of a research and development phase in the development of a conservation program for this sector. The selected buildings were chosen to be representative of multifamily buildings in their service area. The buildings ranged in size from six to 25 units, were all four stories or less, had wood-frame construction (with one exception), and heated with electricity. Ten of the buildings had individual unit domestic hot water heaters; while five buildings had central DHW systems (three electric and two gas). Feasible and cost-effective measures were identified for each building based on an audit and computer simulations. Most measures were installed to increase the energy efficiency of the building shell: window replacement and conversions, ceiling and floor insulation, and low-flow showerheads. Various window measures were the most popular. Several buildings received experimental measures (central DHW heat pumps, exterior Dryvit wall insulation) or retrofits that required major structural rehabilitation (exterior flat roof insulation and new

† ORNL defined the pre-retrofit period as 1982/83 and the post-retrofit period as 1985/86 for their entire sample.

roofs). SCL collected detailed cost information for each retrofit. For example, the utility found that window conversions cost significantly less than window replacements ($\$6.50/ft^2$ vs. $\$11.00/ft^2$). The median cost for all measures in the fifteen buildings was $1526/unit ($\$1.64/ft^2$); the cost of the common measures only was about $1100/unit (excluding experimental measures). In general, retrofit costs were split between SCL and the building owner on a 75/25 basis.

Data/Analysis: SCL collected weekly meter readings in twelve buildings, while the remaining three buildings received more detailed monitoring, including hourly end-use data and indoor temperatures. Consumption data were available for about one year before and after the retrofits. LBL used the energy consumption data for each building derived from SCL's Method 1. Method 1 consisted of a linear regression equation of weekly electricity consumption versus heating degree-days per week to base 65°F for each building before and after the retrofit.

SCL simulated the impact of the planned measures on building energy consumption using the DOE-2 simulation program. However, the measures actually installed differed in almost all buildings from those recommended. LBL entered predicted savings estimates only for those few buildings where actual and recommended measures were similar.

Results: Median electricity consumption decreased by about 12% in the 15 buildings in the year following the retrofits, while consumption decreased by about four percent in seven control buildings during the same period. Using multivariate regression analysis, SCL identified three factors that significantly affected the level of energy savings: 1) electricity consumption before the retrofit, 2) the building's sensitivity to weather, and 3) total heated square footage. Savings and cost-effectiveness varied depending on retrofit strategy. LBL classified the 15 buildings into three basic retrofit strategies: RH, retrofits in conjunction with building renovation or rehab (e.g., insulating the attic while putting on a new roof); SH, envelope shell measures (attic insulation and window measures); and WI, window retrofits only. Buildings that received the window retrofits only (WI) had less variability in energy savings (10 to 17%) and lower payback times (ranging between 12 and 23 years) than the other two groups. High retrofit costs, low electricity prices (about $0.05/kWh), and lower than expected savings were factors that contributed to the long payback times. SCL also noted that there was significant tenant turnover in these buildings (57%).

Based on preliminary analysis of end-use load patterns in the three buildings that were monitored in detail, SCL concluded that 1) the increased winter load is due to space heating, 2) hot water usage is the largest annual load and, 3) the winter and summer morning peaks appear to be driven by hot water usage.

E029.1: Denver CO, - SERI/Denver PHA [57]

Building/Retrofit Description: The Solar Energy Research Institute (SERI) in cooperation with the Denver Housing Authority monitored energy use for 18 months in a high-rise public housing complex occupied by the elderly. The 100-unit complex was built in the late 1970s and has concrete block walls, double-pane windows with thermal breaks, and exterior wall and roof insulation (R-17 and R-12.5 respectively). Each unit has its own individual heating and cooling systems, although the complex is master-metered (the Denver PHA pays all electric utility bills). Hot water is supplied by a central electric resistance boiler. SERI found that the elderly tenants generally kept their apartments between 71°F and 75°F and many residents complained about drafts during winter. The Housing Authority's tight budgetary constraints severely limited possible retrofit options ($3000 for the whole building, or $60/unit). Approximately half of the units received a package of infiltration-reducing measures (i.e., weatherstripping front doors of each unit and stairwell doors on each floor, caulking), while nothing was done in the remaining units.

Data/Analysis: SERI monitored apartment electricity consumption (except for hot water) by sub-metering two panel boxes which effectively split the complex into two groups (SD1 and SD2). Forty-seven units were connected to SD1 (the control group) and 53 units were connected to SD2 (the test group that received the infiltration-reducing measures). In addition, SERI monitored outdoor temperature and whole building peak demand and collected utility bills for the project. The building was monitored in this fashion for about six months (three months before and after the retrofit). SERI analyzed the impact of the retrofit by performing a linear regression of average daily electricity consumption versus outside temperature for both the test and control group for each period. SERI's savings estimates are based principally on a side-by-side comparison of the slopes of the lines of each group in the post-retrofit period. LBL calculated weather-normalized annual electricity consumption for a typical year (using heating degree-days to base 65°F) for each group using parameter estimates from the regression equations before and after the retrofit.

Results: Annual electricity consumption in apartment units ranged between 11760 and 12710 kWh/unit among the two groups, based on regression parameter estimates from three months of monitored data prior to the retrofit (October-December 1986). Annual consumption decreased by about 1400 kWh/unit in the test group and by about 300 kWh/unit in the control group, based on parameter estimates from three months of post-retrofit data. Thus, net savings (test - control group) are about 10 percent. However, LBL does not have much confidence in the savings estimates for the following reasons: 1) short monitoring period (three months before and after) and lack of data from shoulder and summer months, 2) uncertainties associated with the ability of the experimental design (side-by-side groups) to reflect actual effects of infiltration-reducing measures (because of leaks to the external shell and leaks between apartments), and 3) lack of information on other factors that could cause changes in consumption (e.g., apartment vacancies).

OTHER HEAT

X001.1 - X001.9: Sweden - Swedish Council for Building Research [58-60]

Building/Retrofit Description: Nine high-rise buildings in Gothenberg, Sweden, received a series of retrofits during 1983 and 1984 as part of a project initiated by the Swedish Council for Building Research. All nine buildings received a basic group of retrofits, including attic insulation, adjustments to the heating and ventilation systems, flow regulators for tap water, thermostatic radiator valve controls, and weatherstripping. At seven of the structures, combinations of the following measures were also implemented: wall insulation, conversion of windows from double- to triple-glazing, triple-glazing in stair enclosures, and heat pumps.

Data/Analysis: Information on indoor conditions, such as temperature and air change rate, were collected before and after the measures were implemented. Weekly energy consumption and continuous indoor/outdoor temperature measurements were also collected; the study authors used an "energy signature" regression model to weather-normalize energy use.

Results: At buildings which received only the basic group of measures, savings of 14 to 21% were observed. Window conversions were carried out at two buildings: savings here ranged from 8-10%, while energy consumption at two other buildings with heat pump retrofits was reduced 12-13%. Increased glazing in stair enclosures did not significantly change consumption (±3%). Savings ranged from 17 to 40% for various combinations of these measures. The retrofits were expensive, ranging from $550 to over $10,000 per apartment (1985 $). Even though energy prices are higher here than in the U.S. (about $12/MBtu), payback times are still very long, ranging from seven to 38 years.

X002.1 - X002.5: Umea, Sweden - META/Swedish Building Research Council/Umea University [61]

Building/Retrofit Description: The Swedish Building Research Council initiated a project to evaluate the energy savings and economics of various measures in existing housing built in the early 1970s. The complex was located in Umea and consisted of two blocks with 476 units in 31 low-rise buildings. Apartment floor area ranges between 850-970 ft^2. The buildings are relatively massive structures, with floor structure, end walls, and structural inner walls made of concrete. Side walls and attic areas are insulated with mineral wool (R-value of 19) and windows have double-glazing. Space heating and hot water are supplied by a district heating system with hot water distribution. Each building also has a forced ventilation system. Many of the apartment units are occupied by students, which complicates analysis of usage patterns (i.e., a significant fraction of the units are vacant during Christmas holidays and summer breaks). In the fall of 1982, each building received the "basic" program, which included installation of thermostatic radiator valves (TRV), and adjustment of the heating distribution system to optimize TRV performance. In 1984, various individual retrofits (e.g., installation of double plate air-to-air heat exchanger, two kinds of heat pumps, and triple glazing) were installed in one or two buildings as part of a tightly controlled experiment (i.e., matched control reference buildings).

Data/Analysis: Sub-metered energy consumption data were collected weekly for almost three years at the selected test and reference buildings. In addition, data were collected on hot and cold water temperatures, ventilation rates, and outdoor temperature, which enabled researchers to develop a detailed energy balance at both blocks.

Results: Space heat and hot water consumption decreased by about five percent at one block in the year following implementation of the "basic" program; the "basic" program was also the most cost-effective retrofit at this site. Space heat consumption decreased by about four percent in the three buildings that received triple glazing. Space heat and hot water usage declined by about 12 percent in the one building in which the heat exchanger was installed. Savings were substantial in the two buildings that received heat pumps (25 and 23 percent respectively), although the indirect type which used a water/glycol mixture was more cost-effective than the heat pump which was connected with the evaporator directly in the exhaust air duct.

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APPENDIX C: DESCRIPTION OF HEATING SYSTEM RETROFIT MEASURES

Appendix C includes brief descriptions of a number of heating system measures described in this study.

Furnace Retrofits

Central forced-air furnaces are the most common type of home heating equipment in the United States (Fig. C-1).† Warm-air furnaces dominate the single-family market, and are also popular in small and large multifamily buildings (38% of households in two-to-four unit buildings, and 31% of those in buildings with five or more units, have warm-air furnaces). Lower first-cost retrofits that can be implemented include: 1) a basic tune-up, 2) installation of furnace-only vent damper or vent damper installation for both the furnace and hot water vent (Fig. C-2), 3) replacement of standing gas pilot by an intermittent ignition device (Fig. C-3), 4) installation of a vent restrictor, and 5) furnace input de-rating no greater than 20% of existing gas input (Fig. C-4). Savings from vent dampers are strongly influenced by the degree of "communication" (in the form of air exchange) between the furnace room and the main building. Higher first-cost retrofits include: 1) replacement of an existing furnace with a down-sized or higher efficiency furnace, 2) addition of an extended draft hood, 3) use of a condensing-flue heat-extractor to reduce burner on- and off-period flue losses, and 4) addition of a non-condensible (sensible) heat extractor (see Fig. C-5).‡ [1]

Boiler Retrofits

Boilers are the most common heating plant in older multifamily buildings. Most gas-fired boilers are equipped with atmospheric burners, although power burners are increasingly popular because of their improved efficiency (see Fig. C-6 for schematic of atmospheric burner). Power burners typically include at least one of the following features: forced draft, induced draft, premixing burner, or pressure burner (boilers with forced and induced draft systems are illustrated in Figs. C-7 and C-8). For oil-fired burners, the flame retention burner has been found to be an effective retrofit. The flame retention burner produces a compact flame which quickly heats the nozzle spray by creating a rapidly spinning cone of air which causes the air and oil mixture to pass through the flame repeatedly, as opposed to a conventional burner in which the air and oil pass through the flame only once (Fig. C-9).

Heating Distribution Systems

In hot water and steam distribution systems, pipes carry water or steam from the boiler to the areas to be heated. Ducts carry heated air from the furnace to the living space in warm air systems.

Single-Pipe Steam Retrofits

Single-pipe steam (SPS) systems were standard in larger multifamily buildings constructed prior to 1940. Each room radiator is connected to a single pipe which both supplies steam to the radiator and returns the condensed water to the riser (Fig. C-10). A typical SPS-heated building has only one thermostat. The boiler comes on in response to a call for heat, heats the water, and generates steam. SPS buildings often suffer from uneven heating which is caused by large differences in steam arrival times, excessively short boiler cycles, inappropriate radiator sizing, and lack of zone control. The steam balancing retrofit is designed to reduce uneven heating, increase tenant comfort, and save energy by lowering the building's thermostat setting. Proper air venting can be used to minimize differences in steam arrival time and consists of both main line air vents on the main distribution lines and variable air vents on the individual radiators (see Figs. C-11 and C-12 for illustration of effect of air vents). The Minneapolis Energy Office (MEO) recommends main line air vents with large thermostatic steam traps installed on the distribution lines in the basement after the last riser and before the dry return drops into the wet return. [2] Thermostatic radiator vents (TRV) are used to provide individual space temperature control in those apartments that are too hot (Figs. C-13 and C-14). TRVs are usually installed on the largest radiators in the warmer apartments or in rooms where a cooler temperature is desired (e.g., a bedroom). MEO's steam balancing retrofit also includes a remote

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† According to the 1984 RECS Survey, 47% of all U.S. households have a forced air furnace as their main heating equipment (40.7 out of 86.3 million households).

‡ Note that condensing-flue and sensible heat extractor modifications are not covered by an ANSI standard.

sensing thermostat (which is less accessible to tampering) and various boiler cycle control strategies (e.g., cycle holding relay, thermostat location and differential, and timer).

Hot Water System Retrofits

Multizone hot-water distribution systems are common in multifamily buildings constructed since World War II. Figure C-15 shows a schematic of a hot water boiler and controls. Often, the boiler water temperature is controlled by an aquastat, which keeps the water in the system at a constant temperature. Normally, these buildings have one or more main heating distribution loops, from which separate baseboard loops run into each apartment (Fig. C-16). Individual apartments have zone valves and thermostats to regulate the flow of hot water into the baseboard loop. An outdoor reset and cutout control is a particularly cost-effective retrofit in these buildings. Figure C-17 illustrates the basic principle of the outdoor reset, which is to provide the minimum temperature necessary to heat the building in response to changes in outdoor temperature. Note that for cast-iron boilers, the outdoor reset can control the boiler water temperature directly by controlling the firing of the boiler. However, the water in steel fire-tube boilers must be maintained at 140°F or higher to prevent corrosion and thermal stress, thus reset control can be achieved by installing a three-way mixing valve that mixes hot boiler water temperature with cooler return water to provide the desired supply temperature. An outdoor cutout senses the outdoor temperature and automatically shuts off the burner and pump during mild periods in the spring and fall months (e.g., cutout setting of about 55°F).

REFERENCES

1. R. A. Macriss, T. D. Donakowski, and T. A. Zawacki, "Natural Gas and Propane Furnace Retrofit Study," Institute of Gas Technology, March 1984.

2. G. Peterson, "Achieving Even Space Heating in Single Pipe Steam Buildings," Minneapolis Energy Office, TR 85-8-MF, December 1985.

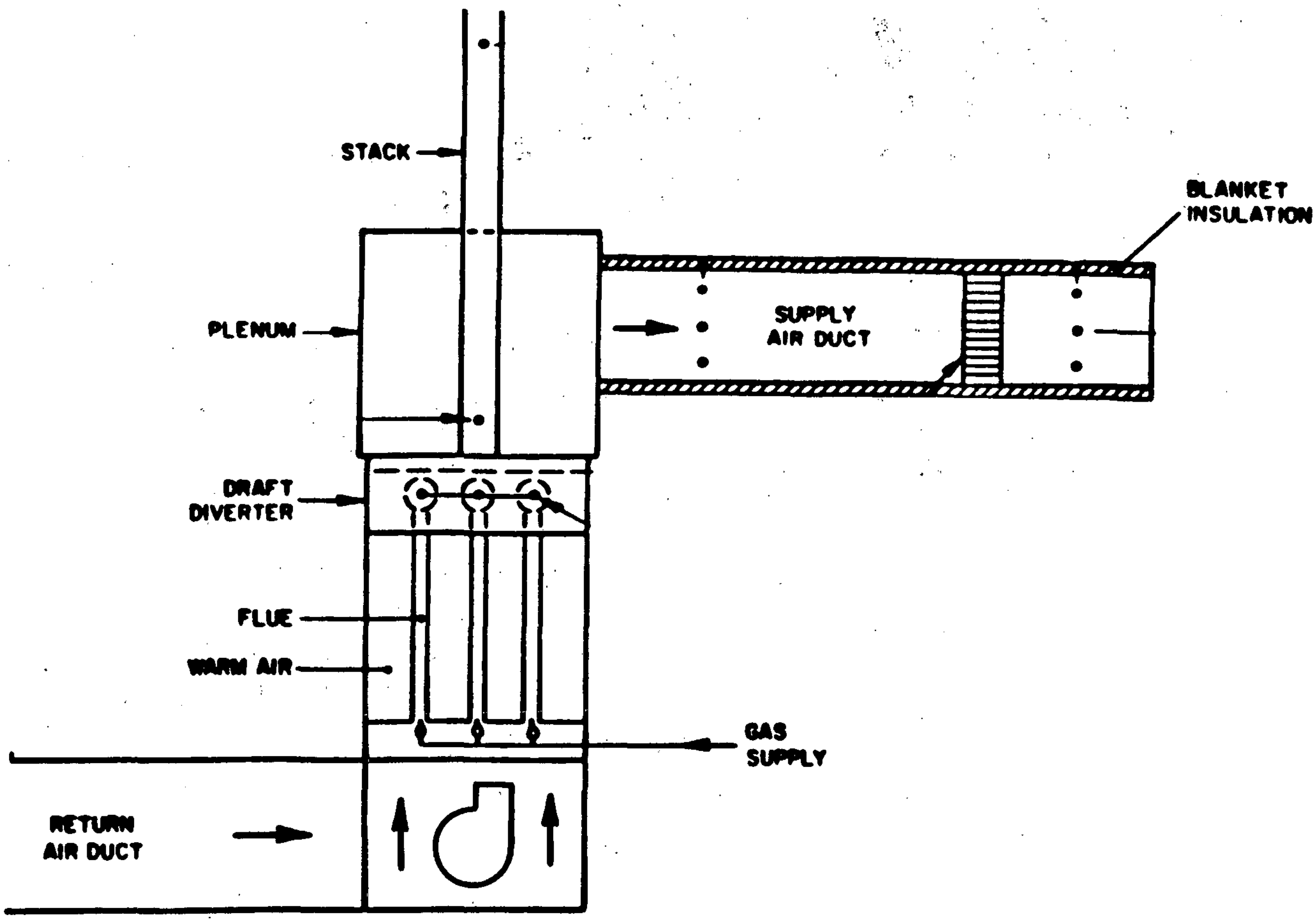


Fig. C-1. Schematic of warm-air furnace installation.
Source: R.A. Macriss, T.D. Donakowski, and T.A. Zawacki, "Natural Gas and Propane Furnace Retrofit Study," Institute of Gas Technology, March 1984.

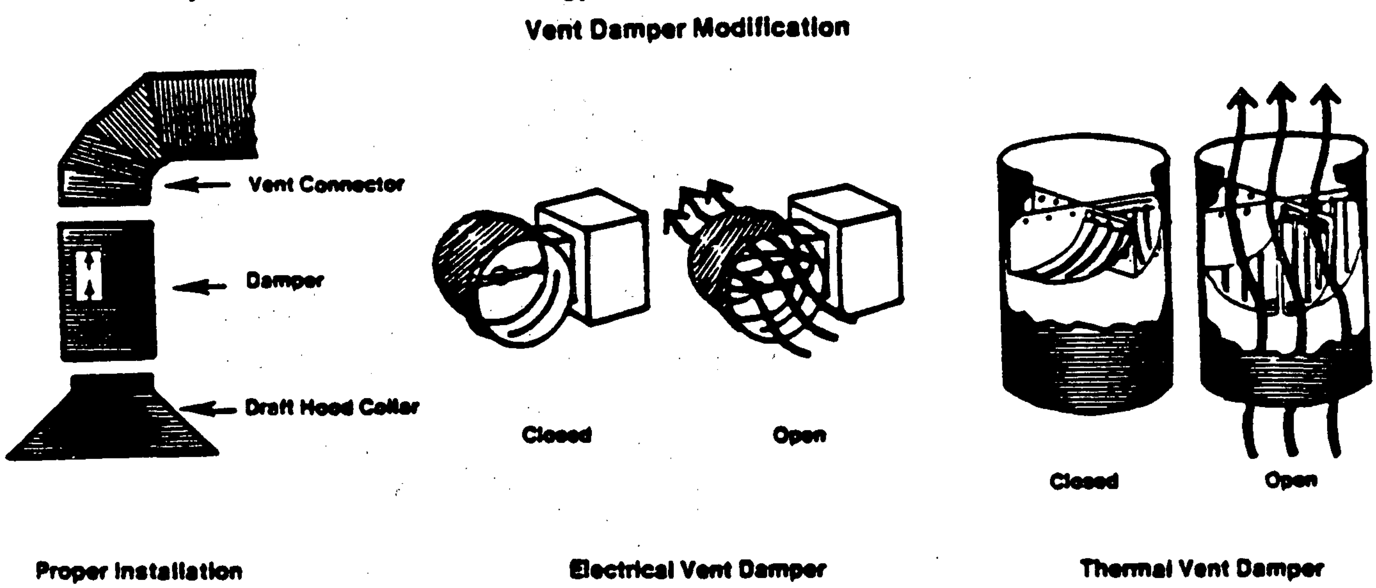


Fig. C-2. Flue openings can be modified by installation of a thermal or electric vent damper. Commonly available sizes range from three to eight inches in diameter.
Source: Minnesota Department of Public Service Energy Division, "Multifamily Building Energy Audit Technical Manual." February 1987.

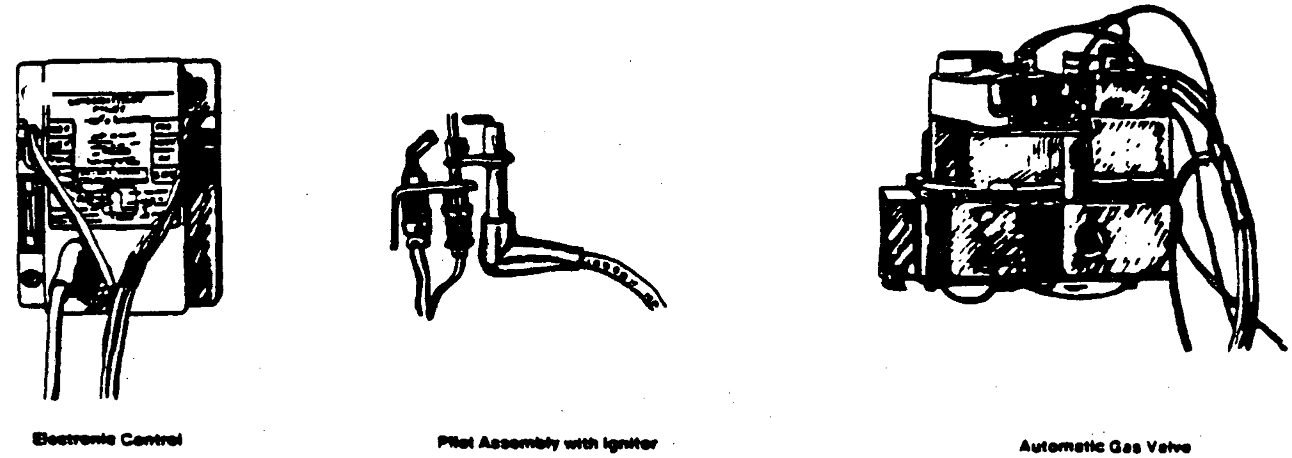


Fig. C-3. Components of of an electronic ignition system; retrofit should be considered if the gas valve on a heating system needs replacement (10 years old or more).
Source: Minnesota Department of Public Service Energy Division, "Multifamily Building Energy Audit Technical Manual," February 1987.

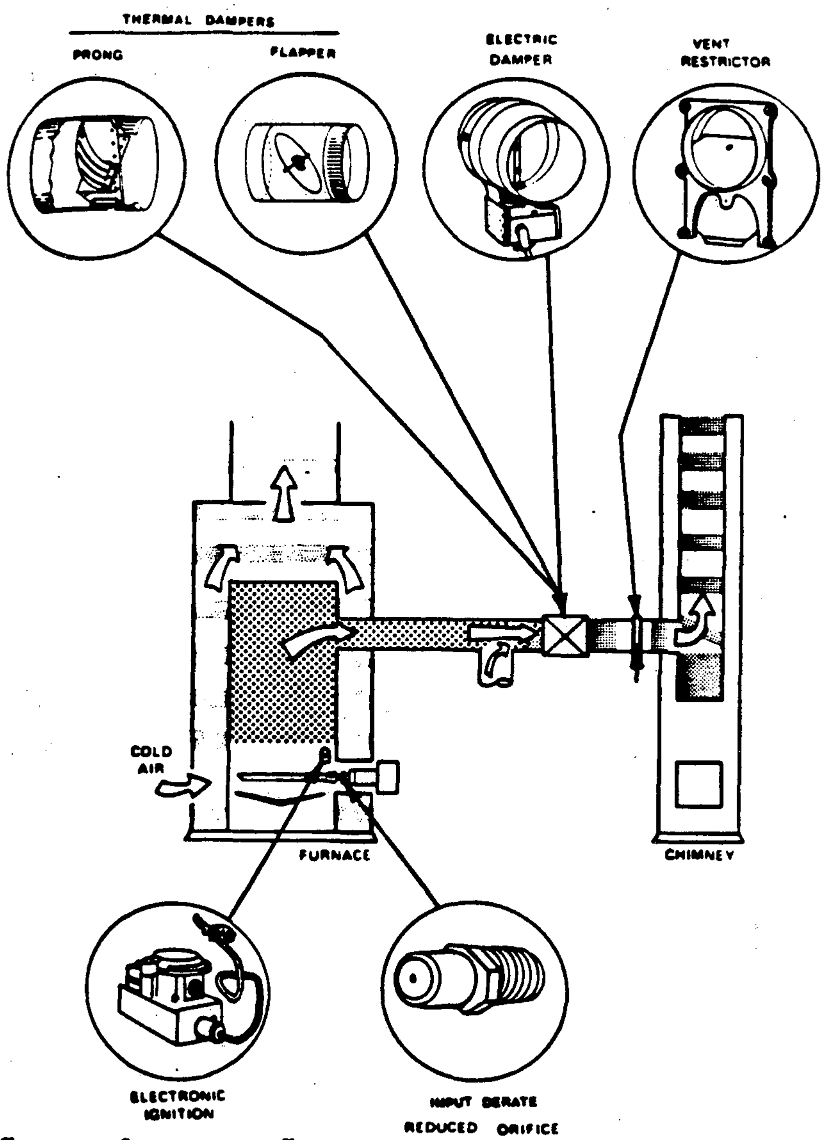


Fig. C-4. Lower first-cost furnace retrofits
Source: Institute of Gas Technology, "Natural Gas and Propane Furnace Retrofit Study," March 1984.

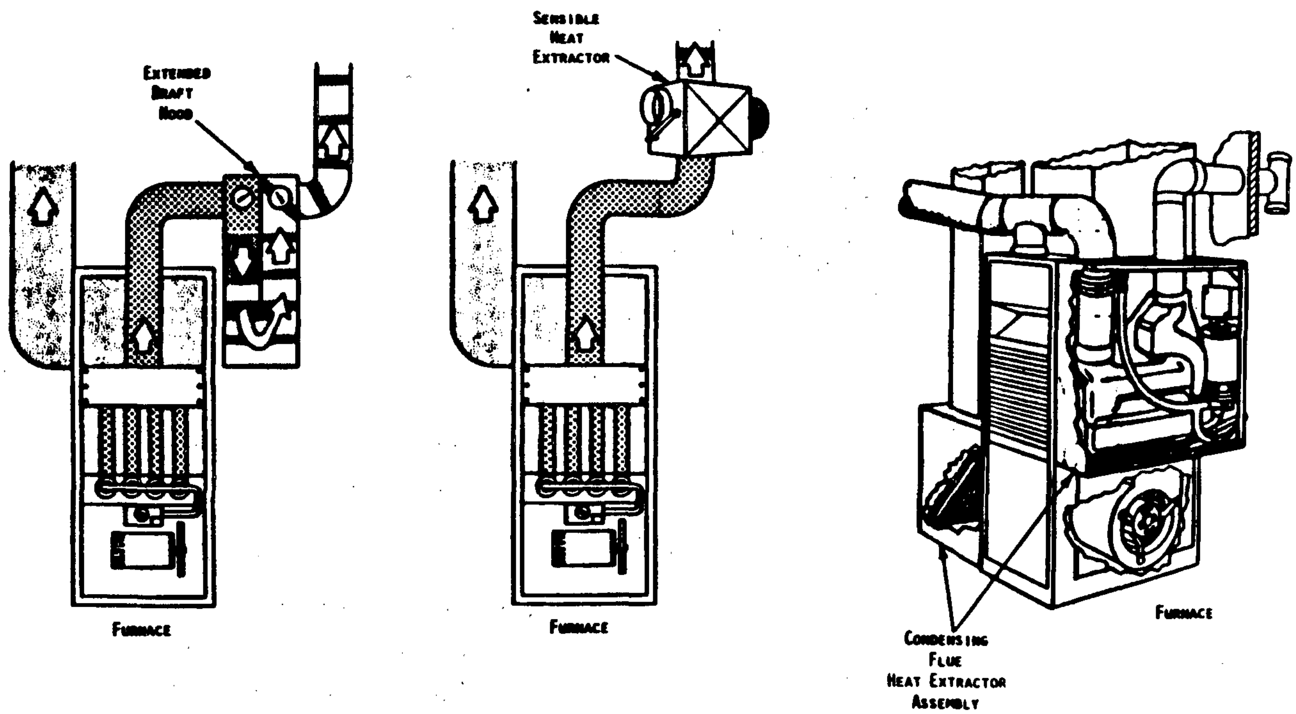


Fig. C-5. Higher first-cost furnace retrofits.
Source: R.A. Macriss, T.D. Donakowski, and T.A. Zawacki, "Natural Gas and Propane Furnace Retrofit Study," Institute of Gas Technology, March 1984.

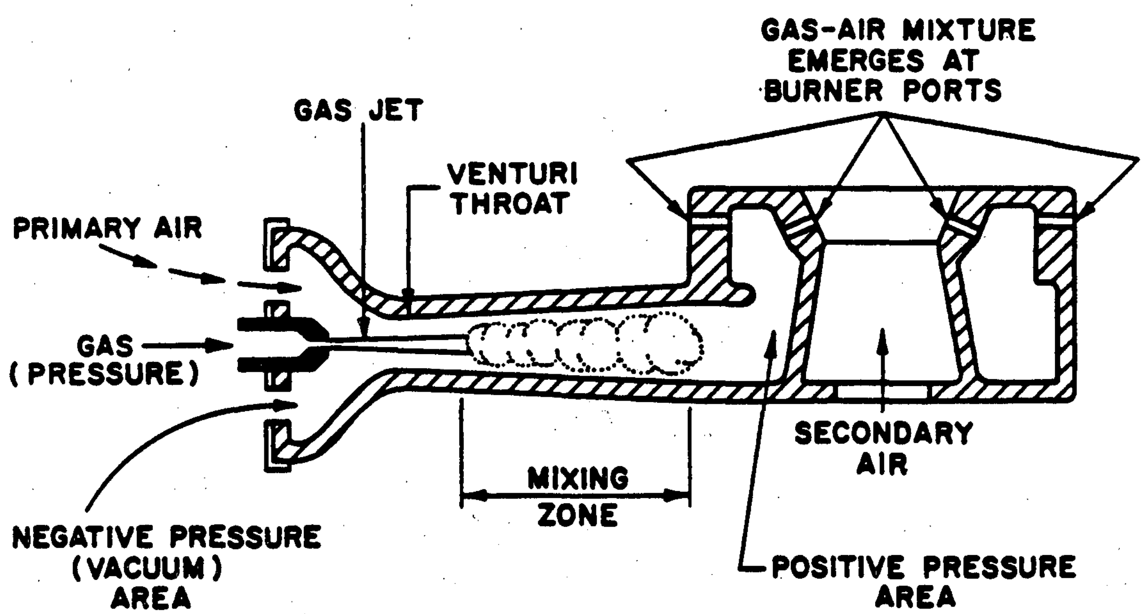


Fig. C-6. Injection of primary air in an atmospheric burner.
Source: Minnesota Department of Public Service Energy Division, "Multifamily Building Energy Audit Technical Manual," February 1987.

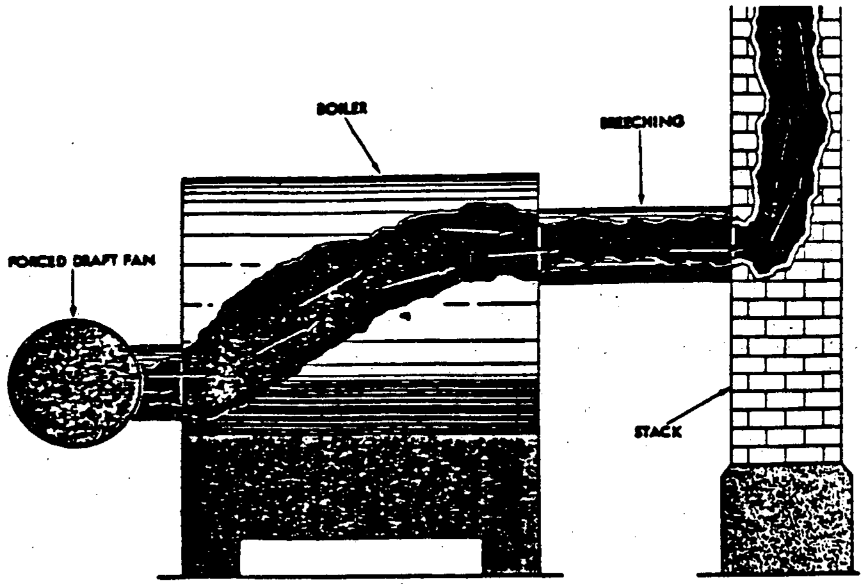


Fig. C-7. Power burners with forced draft system.
Source: Minnesota Department of Public Service Energy Division, "Multifamily Building Energy Audit Technical Manual," Februarv 1987.

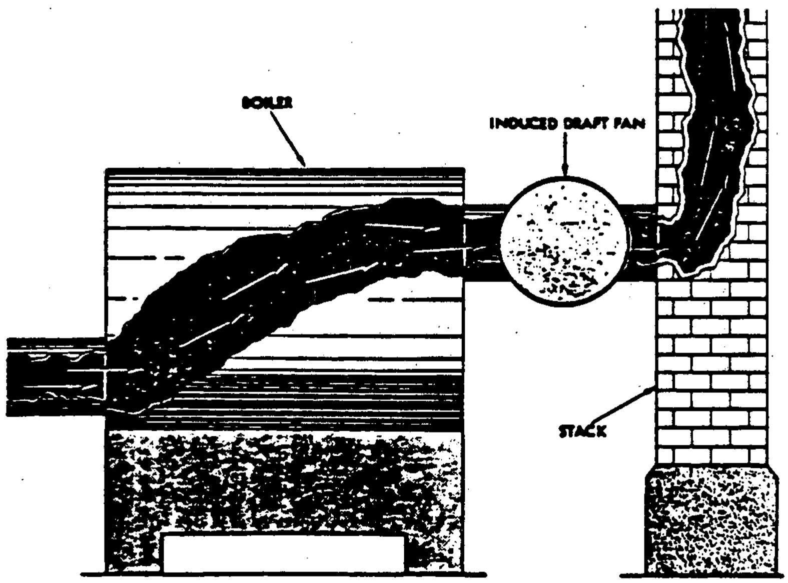


Fig. C-8. Power burners with induced draft system.
Source: Minnesota Department of Public Service Energy Division, "Multifamily Building Energy Audit Technical Manual," February 1987.

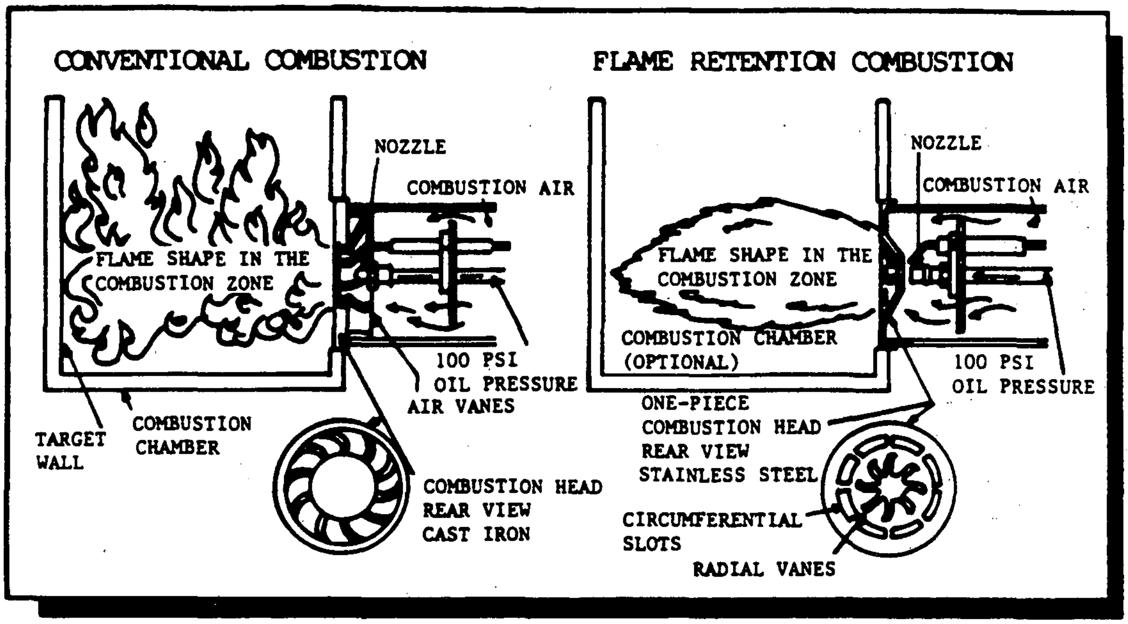


Fig. C-9. Schematic of conventional oil-fired burner versus flame retention head burner. Source: Alliance to Save Energy, "Technician's Manual: Low-Income Oil Heat Retrofit Program," December 1985.

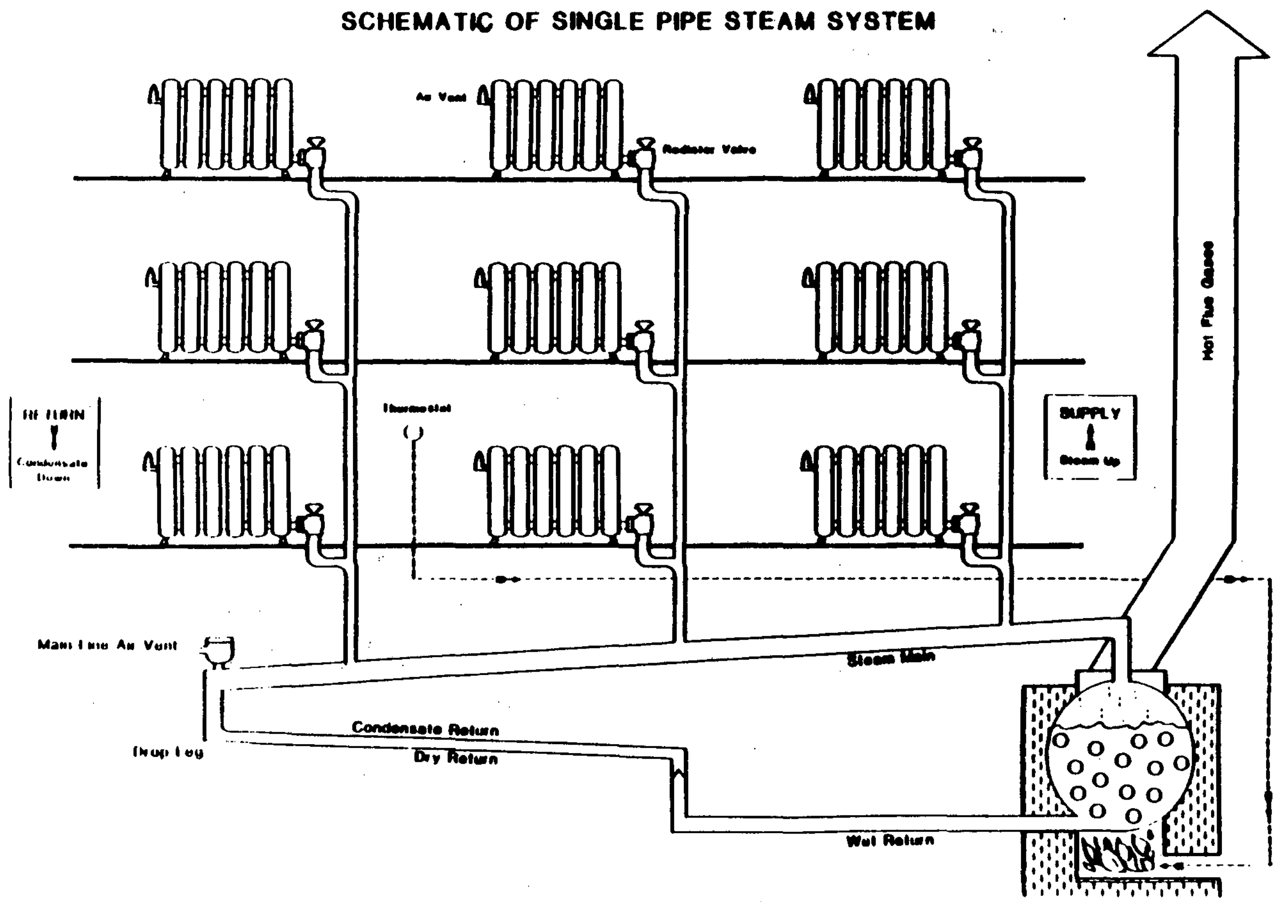


Fig. C-10. Schematic of single pipe steam system. Source: G. Peterson, "Achieving Even Space Heating in Single Pipe Steam Buildings," Minneapolis Energy Office, TR 85-8-MF, December 1985.

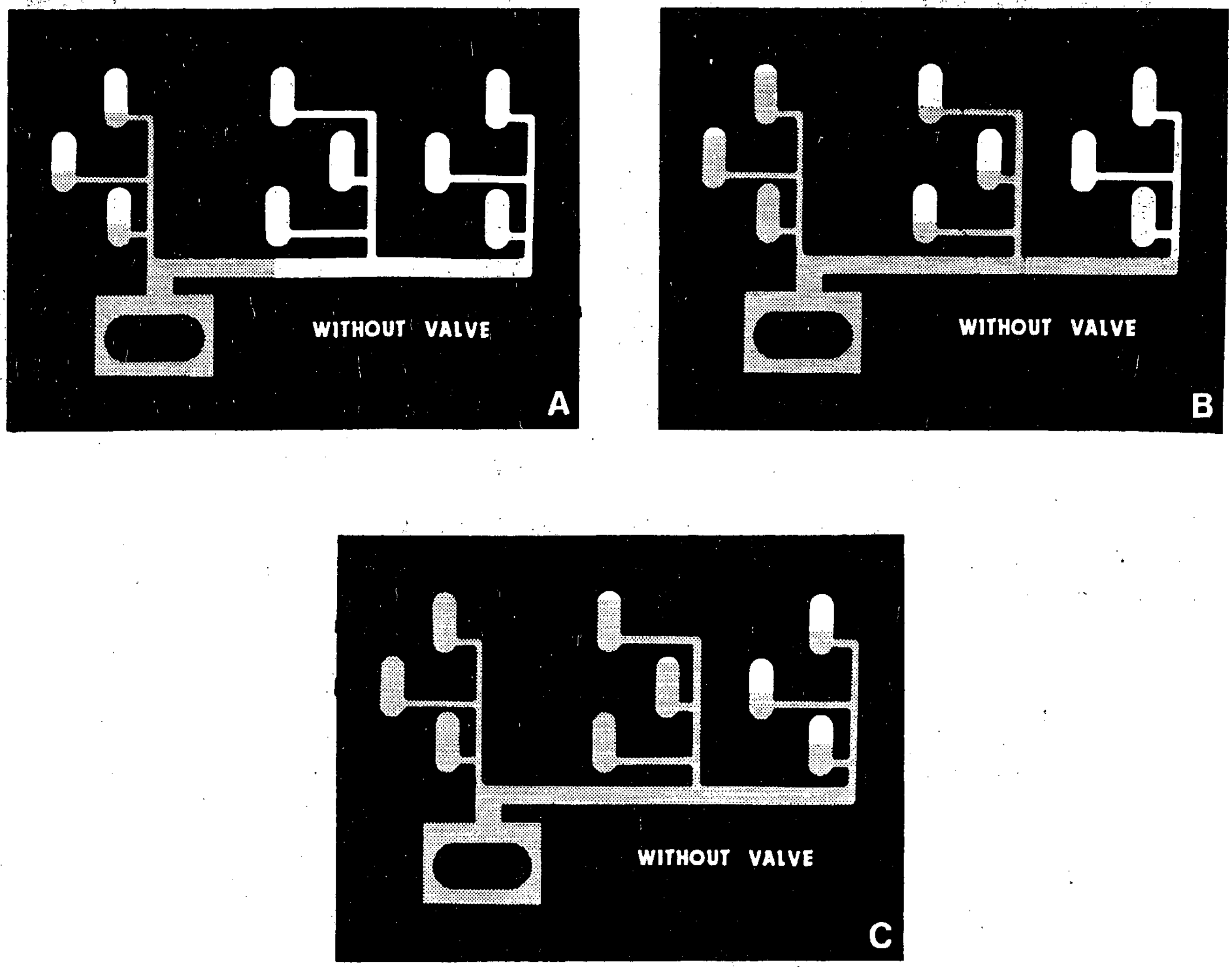


Fig. C-11. Steam fill pattern in building without main line air vents.
Source: G. Peterson, "Achieving Even Space Heating in Single Pipe Steam Buildings," Minneapolis Energy Office, TR 85-8-MF, December 1985.

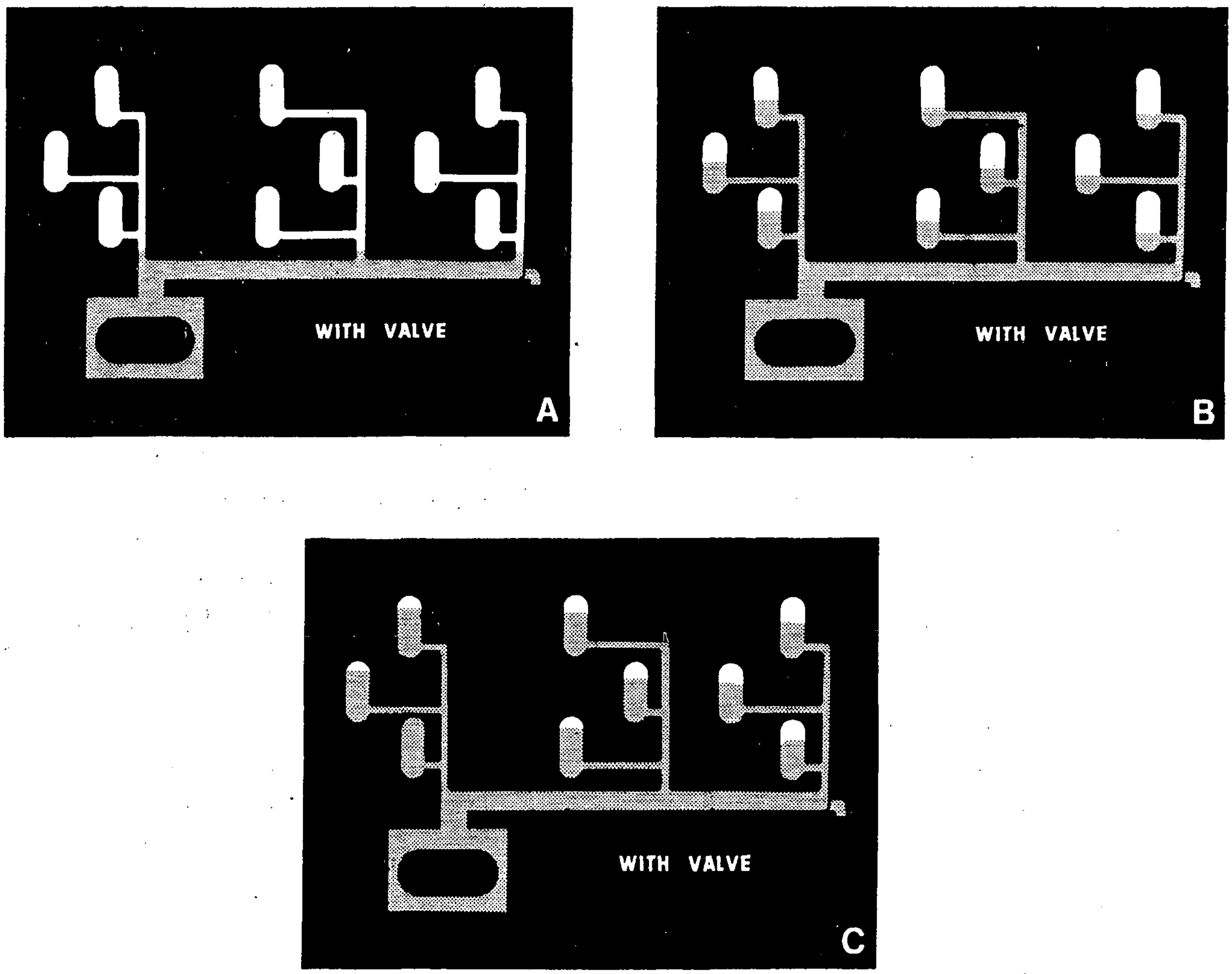
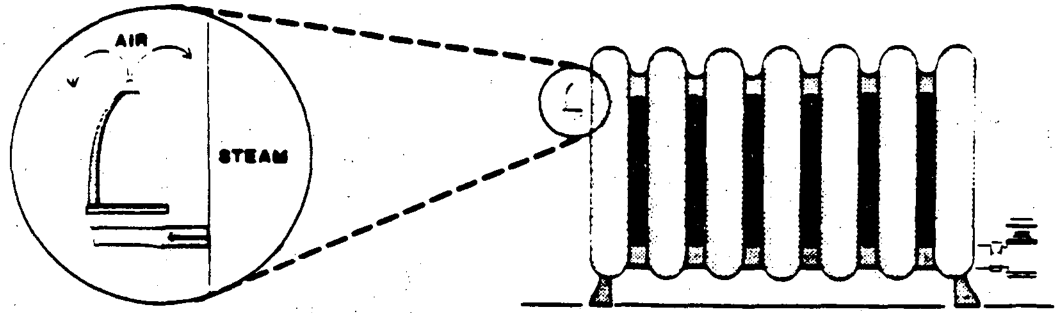


Fig. C-12. Steam fill pattern in building with main line air vents.
Source: G. Peterson, "Achieving Even Space Heating in Single Pipe Steam Buildings," Minneapolis Energy Office, TR 85-8-MF, December 1985.

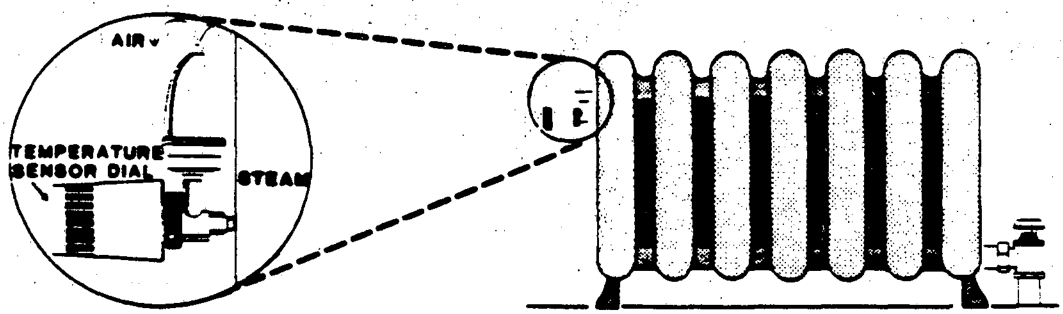
Radiator Vents



Steam can only enter a radiator by first displacing any air which may be inside the radiator. In single pipe steam systems this is done with an air vent which usually resembles a tiny silver rocket ship on the side of the radiator. The air vent allows air to leave the radiator, and steam to fill it. When steam actually reaches the air vent, it closes, preventing the escape of steam from the radiator. As the steam condenses it supplies heat to your apartment.

IF ANY AIR VENTS IN YOUR UNIT DO NOT EMIT AIR, OR IF THEY EMIT STEAM, CALL YOUR MAINTENANCE PERSON OR CARETAKER IMMEDIATELY ABOUT REPLACEMENT.

Thermostatic Radiator Vents



Thermostatic Radiator Vents, or TRV's are useful for providing comfortable space temperatures in those apartments which consistently overheat. If one of the radiators in your apartment is equipped with a TRV you can adjust the temperature in your unit by turning the sensor dial up or down depending on the desired condition. Do not expect instant results. Leave the dial at the new setting for 24 hours before readjusting.

Fig. C-13. Description of radiator vents and thermostatic radiator vents.
Source: G. Peterson, "Achieving Even Space Heating in Single Pipe Steam Buildings," Minneapolis Energy Office, TR 85-8-MF, December 1985.

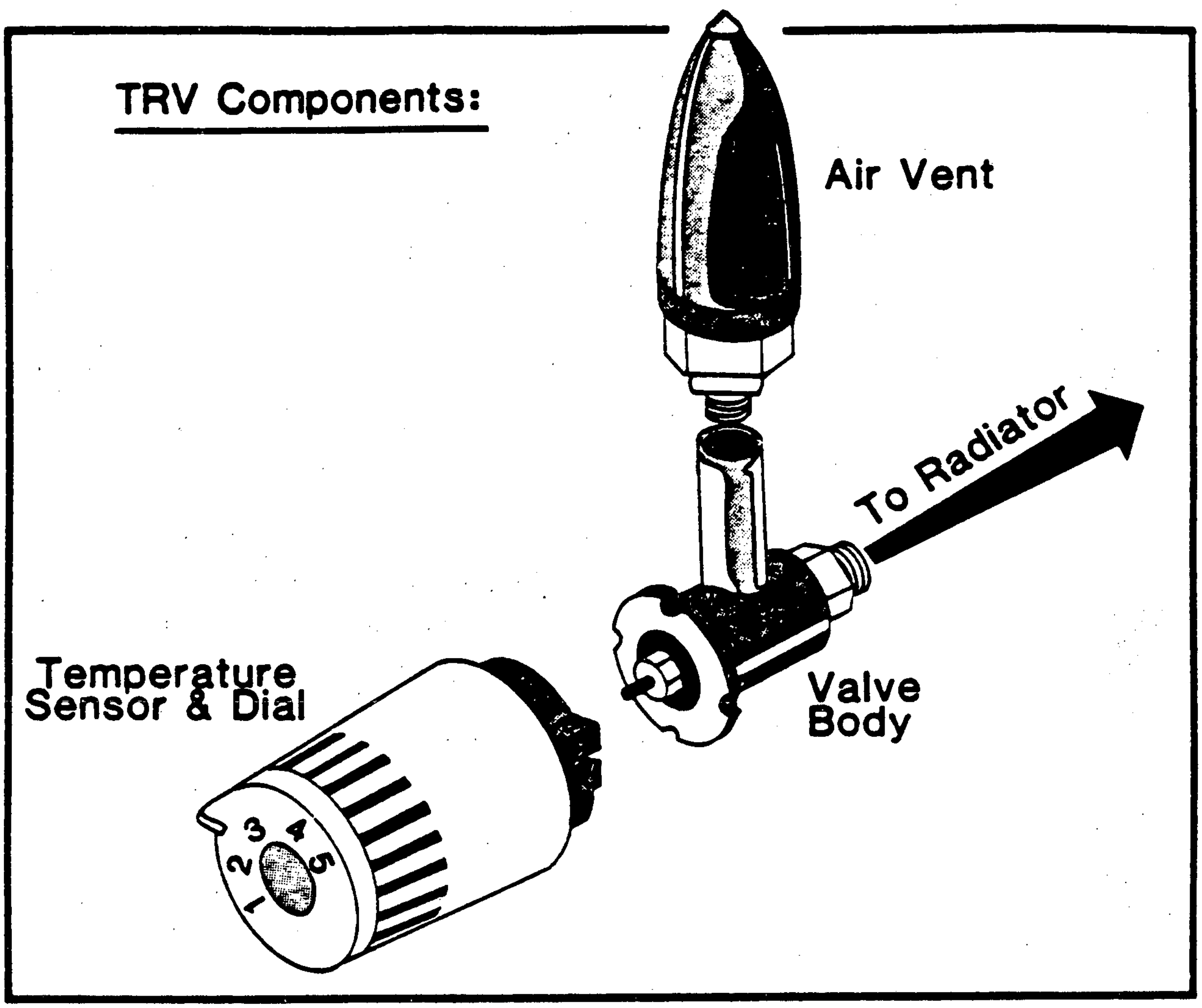


Fig. C-14. Components of thermostatic radiator vents (TRV). TRVs can help control the temperature in steam heated buildings by limiting the amount of steam that a radiator receives. TRVs only vents air if the apartment needs heat according to the setpoint on the temperature dial. If the apartment is not calling for heat, the TRV closes and the radiator is air locked.
Source: G. Peterson, "Achieving Even Space Heating in Single Pipe Steam Buildings," Minneapolis Energy Office, TR 85-8-MF, December 1985.

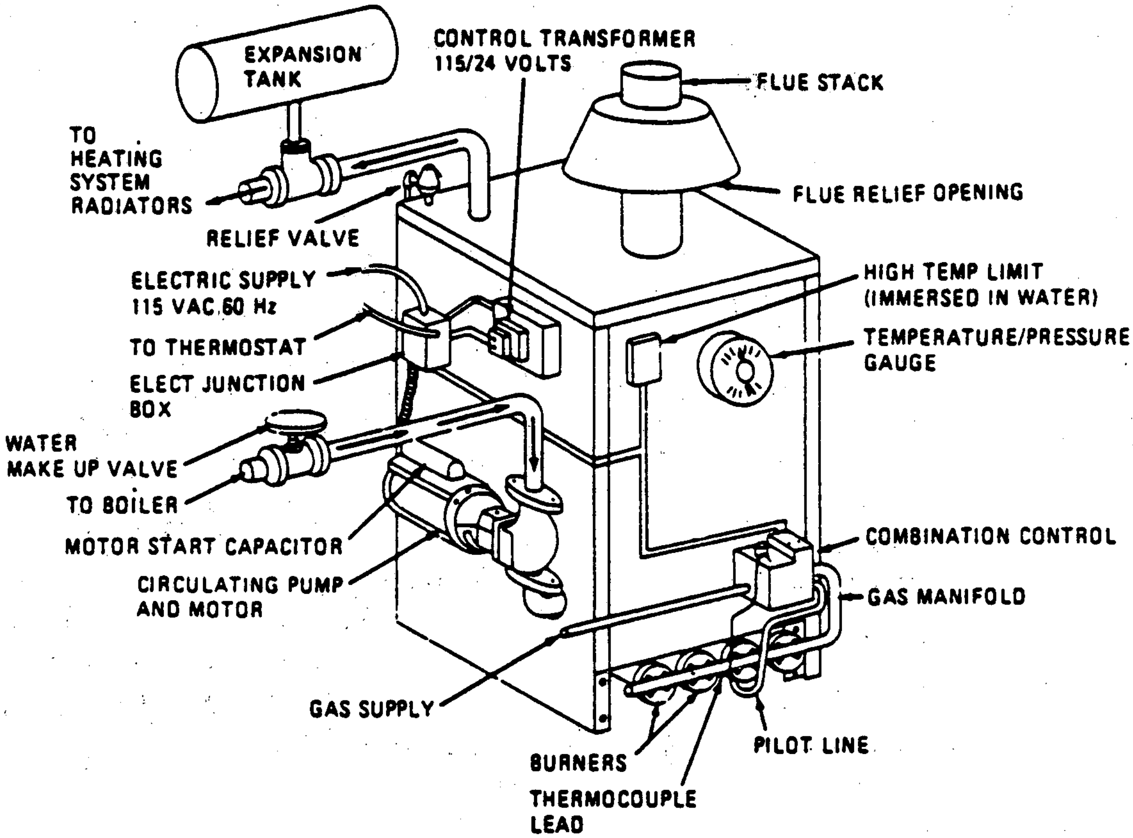


Fig. C-15. Schematic of a hot water boiler and controls.
Source: Minnesota Department of Public Service Energy Division, "Multifamily Building Energy Audit Technical Manual," February 1987.

Hydronic Heating System

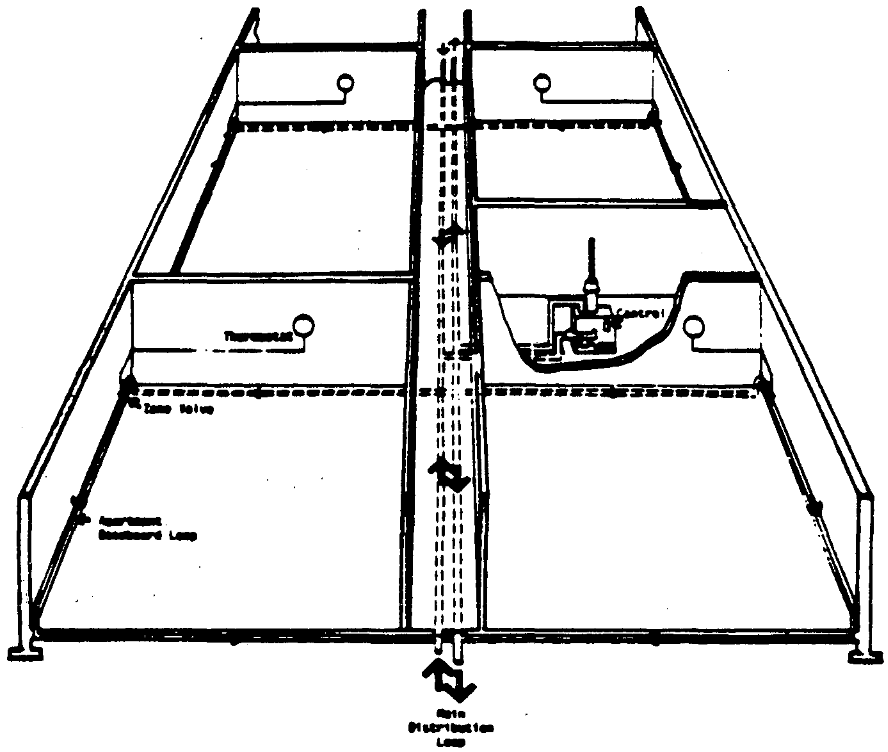


Fig. C-16. Schematic of a hot water distribution system.
Source: M. Hewett and G. Peterson, "Measured Energy Savings from Outdoor Resets in Modern, Hydronically Heated Apartment Buildings," Minneapolis Energy Office, August 1984.

Control of Water Supply Temperature

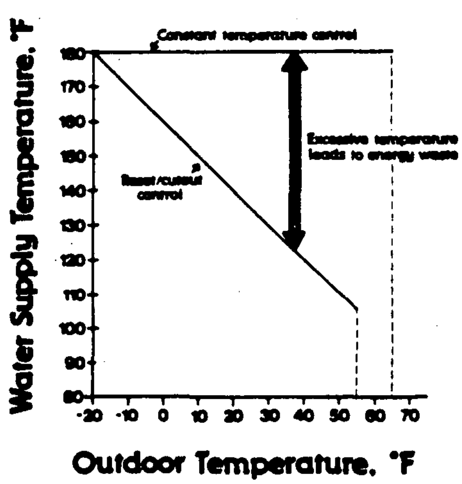


Fig. C-17. Water supply temperatures versus outdoor temperature with aquastat (constant temperature control) and outdoor reset controls.
Source: M. Hewett and G. Peterson, "Measured Energy Savings from Outdoor Resets in Modern, Hydronically Heated Apartment Buildings," Minneapolis Energy Office, August 1984.

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