Title
Energy Impacts of Efficient Refrigerators in the Pacific Northwest

Authors
Sherman, M.
Modera, M.
Hekmat, D.

Publication Date
1985-04-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE
DIVISION

ENERGY IMPACTS OF EFFICIENT REFRIGERATORS IN THE PACIFIC NORTHWEST

M. Sherman, M. Modera, and D. Hekmat

April 1985

APPLIED SCIENCE
DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

LBL-19571
EEB-EPB-85-12

ENERGY IMPACTS OF EFFICIENT REFRIGERATORS IN THE PACIFIC NORTHWEST

Max Sherman
Mark Modera
Dariush Hekmat

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

April 1985

This work was supported by the Bonneville Power Administration, Portland, Oregon, under contract No. DE-AI79-84BP16357, and by the Assistant Secretary for Conservation and Renewable Energy, of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

ABSTRACT

The energy consumed by appliances is almost completely converted to heat, and therefore offsets heating loads during the winter and increases cooling loads during the summer. Because of this, the overall energy impact of installing energy-efficient appliances cannot be determined directly from their energy consumption savings. This report examines the overall energy impacts of two energy-efficient refrigerators in four types of houses with and without space cooling equipment. The heating and cooling loads of each of the houses are determined with an hour-by-hour simulation program (TRNSYS) for three climates in the Pacific Northwest. These simulations show that the net energy savings for both refrigerators is approximately one half the gross energy savings (savings due to the reduction in consumption). They also show that the energy savings is considerably larger for well insulated houses, and for houses with space cooling equipment. It is found that for houses without space cooling the percentage of the gross savings achieved (normalized net savings) is directly correlated with the length of the non-heating season.

OBJECTIVE

The purpose of this study was to determine the impact of energy-efficient refrigerators on the space heating and space cooling requirements of single-family homes in the Pacific Northwest. The objective is to quantify the overall energy savings that are realized when efficient refrigerators are installed in these houses.

BACKGROUND

As stated in action item 4.2 of the Northwest Power Planning Council's "Two-Year Action Plan",[1]

> "Bonneville shall ... fund a field research project which assesses the effect of energy-efficient appliances, including heat-pump water heaters, on the space heating requirements of fully weatherized residential buildings and new residential buildings that meet the Council's model standards."

The effect of energy-efficient appliances on space heating and cooling is an important issue for the prediction of future regional energy use, as well as for the determination of the cost-effectiveness of conservation programs and appliance efficiency standards.

Because the energy consumed by an appliance is almost completely converted into heat, and therefore into an internal heat gain to the building, the overall energy impact of a more efficient appliance cannot be determined directly from the reduction in consumption. The internal gains reduce the amount of heating required in the winter, and increase the amount of heat that must be removed during the summer. A decrease in consumption for an appliance thus corresponds to a decrease in internal gain, and thus an increase in heating load and decrease in cooling load.

To meet the stated objective, the Bonneville Power Administration (BPA) requested the Lawrence Berkeley Laboratory (LBL) to determine the overall energy impacts of installing energy efficient refrigerators in several types of houses in the Pacific Northwest. Specifically, BPA requested calculations for two levels of insulation and air tightness for both new and existing houses, in three climate zones, with two different levels of internal gain, for two different efficient refrigerators, and considering houses with and without air conditioning. The specific requirements are included in the appendix.

APPROACH

The Lawrence Berkeley Laboratory, using the simulation program TRNSYS,[2] estimated the heating and cooling loads for houses with two types of energy-efficient refrigerators, as well as with the standard refrigerator. The TRNSYS program simulates heating and cooling loads on a hourly basis, using the ASHRAE response factor method to calculate heat transfer through walls.[3] It treats solar gains and internal gains separately, and uses the Lawrence Berkeley Laboratory model to predict air infiltration.[4,5] For each of the house types in each of the three climates, 8760 hour (one year) simulations were performed using Typical Meteorological Year (TMY) weather data.[6]

For all simulations the reduction in refrigerator consumption was assumed to correspond to a reduction in internal gain. The two base levels of internal gain chosen imply different levels of overall appliance consumption, corresponding to the Super Good Cents program and the Model Conservation Standards.[7,8] The internal gains from people and appliances, including the gains from the refrigerators, were assumed to be constant both on a daily and seasonal basis. A more detailed simulation of the internal gains would be beyond the level of detail used for the remainder of the simulation, although several sensitivity runs were performed to examine the effect of seasonal variations in refrigerator consumption. These runs examined the effect of indoor temperature on refrigerator consumption, assuming 25% higher consumption during the non-heating season for houses without air conditioning (the indoor temperature differs only 5 ^{o}C (9 ^{o}F) between summer and winter for air conditioned houses.)

Heating Assumptions

In determining the overall energy savings for each of the refrigerators under different conditions, the net savings corresponds to the reduction in electrical energy delivered to houses with 100%-efficient electric resistance heating. The savings will be higher in houses with heat pumps, as the increase in space heating load is divided by the COP to obtain the heating consumption increase. For houses that are heated with gas or other fuels, the reduction in electrical energy delivered will be equal to the reduction in refrigerator consumption, and the space heating penalty will appear in the consumption of the heating fuel (which must be determined from the efficiency of the heating system). For any heating system (electric or other fuel) the overall energy savings attributable to the refrigerator will decrease as the efficiency of the heating system decreases. Although beyond the scope of this study, an economic comparison based on the relative cost of electricity (vs. other heating fuels), as well as a comparison based on *primary* energy consumption, are logical extensions of this work.

Air-Conditioning Assumptions

In determining the savings for air conditioned houses the following assumptions were made:

1) The house is centrally air conditioned with a unit that can always meet the load,
2) The total system COP of the air conditioner is 2.0,
3) The interior set-point is 25°C (77°F), independent of humidity,
4) There is no economizer cycle on the air conditioner, and
5) Natural ventilation is *not* used to mitigate cooling loads.

The analysis of the energy impact for a house having *room* air conditioning is not well-defined. A room air conditioner is normally used to keep a sub-section of the house (e.g. the master bedroom or living room) cool. This is usually achieved by isolating that sub-section from the rest of the house. If it is assumed that the sub-section being cooled does not include the kitchen (i.e., the refrigerator), the presence of an energy-efficient refrigerator will not affect the cooling load, and the overall energy savings will be equal to that for houses without air conditioning. If, on the other hand, the sub-section being cooled includes the refrigerator, the cooling load will be affected in the same manner as for the central air conditioning case, thereby implying the that the energy savings will be the same as that for centrally air-conditioned houses (except when the COP of the room air conditioner is not the same as the COP of the central system). A full analysis of room air conditioners would require a multi-zone simulation, which is beyond the scope of this study.

RESULTS

Tables 1-3 contain the simulation results for the three climates: Portland, OR, Spokane, WA, and Missoula, MT, respectively: the *a* tables contain the results for houses with heating only (i.e. assuming no cooling equipment) and the *b* tables contain the results for houses with central air conditioning.

The following list describes each column in Tables 1-3. The interpretation of each column is the same for cooling as for heating except as noted:

1) "House" is for the type of single-family (detached) construction: "TE" indicates typical existing home based on the 1979/80 regional survey; "EE" indicates existing homes that have taken maximal advantage of weatherization; "TN" indicates typical new home based on the 1980 Oregon Uniform Building Code; "EN" indicates energy efficient new construction as per the Model Conservation Standard (MCS).
2) "Int Gain" is the level of free heat assumed: "High" indicates 21 kWh/day (72 kBTU/day) including refrigerator type "0" as assumed in the Bonneville Power Administration Super Good Cents Program; "Low" indicates 14 kWh/day (48 kBTU/day) including refrigerator type "0" as assumed by the Council in developing the Model Conservation Standards for new residential buildings. (Note that the CEC uses 25 kWh/day (86 kBTU/day) and a standard DOE-2 assumption is 20 kWh/day (68 kBTU/day).)

3) "Refrigerator" denotes the type of refrigerator used: "0" indicates consumption of 1150 kWh/year (i.e. reference case); "1" indicates consumption of 880 kWh/yr corresponding to best U.S. model (i.e. savings of 270 kWh/yr compared to average); "2" indicates consumption of 580 kWh/yr corresponding to best Japanese model (i.e. savings of 570 kWh/yr).

4) "Heating Load" is the calculated heating load assuming a 20 ^{O}C (68 ^{O}F) set-point. For *b* tables "Cooling Load" is the cooling load assuming a 25 ^{O}C (77 ^{O}F) cooling set-point.

5) "Heating Demand" is the percent of the year (i.e. yearly hours) that there is a heating load (or, equivalently, that the heating system would be on). For the the *b* tables the "Cooling Demand" is the percent of the year that there is a cooling load.

6) "Heating Season" is the number of days of the year on which there is any heating load at all. This value corresponds to the common term, "Length of heating season". Analogously, "Cooling Season" is the number of days of the year on which there is a cooling load.

7) "Net Savings" is the net electrical energy savings attributable to that refrigerator compared to a standard refrigerator. For the *b* tables this includes both heating and cooling. (This is the only column in the *b* tables that combines heating and cooling.) Column 7a (i.e. [kWh]) gives the net amount of energy saved; column 7b (i.e. [%]) displays the savings as a percentage of the gross savings (reduction in energy consumption relative to standard model) of the refrigerator.

8) "% Savings/(100-% Year)" is the ratio of the net savings to the fraction of the year that the heating system is not in operation as determined from Heating Demand column for the standard model refrigerator. This column does not appear in the *b* tables.

9) "% Savings/% non-HS" is the ratio of the net savings to the fraction of the year in which there is no heating load, as determined from Heating Season column for the standard model refrigerator. This column does not appear in the *b* tables.

10) "Decrease in Season" is the decrease in the length of the cooling season (measured in number of days containing a cooling load) caused by the installation of the energy efficient refrigerator. This column does not appear in the *a* tables.

TABLE 1a: Net Energy Savings for Efficient Refrigerators in Portland, OR for Houses without Space Cooling									
House	Int Gain	Refrig erator	Heating Load	Heating Demand	Heating Season	Heating Net Savings		% Savings / 100-%year	% Savings / % non-HS
(a)	(b)	(c)	[kWh]	[% yr]	[days]	[kWh]	[%]		
TE	High	0	13370	51.3	244	-	-	-	-
TE	High	1	13530	51.6	245	110	40.7	0.84	1.23
TE	High	2	13710	51.9	247	230	40.4	0.83	1.22
TE	Low	0	14940	54.4	259	-	-	-	-
TE	Low	1	15110	54.6	260	100	37.0	0.81	1.27
TE	Low	2	15310	55.0	263	200	35.1	0.77	1.21
EE	High	0	6677	40.4	194	-	-	-	-
EE	High	1	6810	40.8	195	137	50.7	0.85	1.08
EE	High	2	6960	41.4	196	287	50.4	0.85	1.08
EE	Low	0	8003	44.0	212	-	-	-	-
EE	Low	1	8151	44.6	214	122	45.2	0.81	1.08
EE	Low	2	8315	45.0	216	258	45.3	0.81	1.08
TN	High	0	7287	41.7	200	-	-	-	-
TN	High	1	7423	42.0	201	134	49.6	0.85	1.10
TN	High	2	7577	42.4	203	280	49.1	0.84	1.09
TN	Low	0	8645	45.4	218	-	-	-	-
TN	Low	1	8796	45.8	220	119	44.1	0.81	1.10
TN	Low	2	8963	46.3	222	252	44.2	0.81	1.10
EN	High	0	3555	35.3	176	-	-	-	-
EN	High	1	3671	35.7	178	154	57.0	0.88	1.10
EN	High	2	3798	36.4	179	327	57.4	0.89	1.11
EN	Low	0	4704	40.1	197	-	-	-	-
EN	Low	1	4836	40.6	201	138	51.1	0.85	1.11
EN	Low	2	4985	41.1	204	289	50.7	0.85	1.10

(a) **TE**=Typical Existing, **EE**=Efficient Existing (i.e. weatherized), **TN**=Typical New, and **EN**=Efficient New (i.e., superinsulated MCS).

(b) **High**=nominal internal gain of 72 kBTU/day and **Low**=nominal internal gain of 48 kBTU/day.

(c) **0**=typical new refrigerator consumption of 1150 kWh/year, **1**=880 kWh/year (best US model) and **2**=580 kWh/year (best Japanese model).

TABLE 1b: Net Energy Savings for Efficient Refrigerators in Portland, OR for Houses with Space Cooling								
House	Int Gain	Refrig erator	Cooling Load	Cooling Demand	Cooling Season	Combined Net Savings		Decrease in season
(a)	(b)	(c)	[kWh]	[% yr]	[days]	[kWh]	[%]	[days]
TE	High	0	2631	10.8	54	-	-	-
TE	High	1	2577	10.6	53	137	50.7	1
TE	High	2	2516	10.3	52	288	50.4	2
TE	Low	0	2143	8.9	44	-	-	-
TE	Low	1	2095	8.9	44	124	45.9	0
TE	Low	2	2043	8.7	42	250	43.9	2
EE	High	0	3365	16.8	80	-	-	-
EE	High	1	3281	16.4	78	179	66.3	2
EE	High	2	3188	15.9	76	376	65.9	4
EE	Low	0	2616	13.3	66	-	-	-
EE	Low	1	2542	13.0	64	159	58.9	2
EE	Low	2	2463	12.7	63	335	58.7	3
TN	High	0	3252	15.9	76	-	-	-
TN	High	1	3172	15.5	73	174	64.4	3
TN	High	2	3085	15.0	71	364	63.8	5
TN	Low	0	2537	12.7	63	-	-	-
TN	Low	1	2466	12.5	61	155	57.2	2
TN	Low	2	2391	12.1	60	325	57.0	3
EN	High	0	3331	19.6	87	-	-	-
EN	High	1	3228	18.9	84	206	76.1	3
EN	High	2	3116	18.4	84	435	76.2	3
EN	Low	0	2440	14.7	70	-	-	-
EN	Low	1	2355	14.2	67	180	66.9	3
EN	Low	2	2267	13.7	64	374	65.6	5

(a) **TE**=Typical Existing, **EE**=Efficient Existing (i.e. weatherized), **TN**=Typical New, and **EN**=Efficient New (i.e., superinsulated MCS).

(b) **High**=nominal internal gain of 72 kBTU/day and **Low**=nominal internal gain of 48 kBTU/day.

(c) **0**=typical new refrigerator consumption of 1150 kWh/year, **1**=880 kWh/year (best US model) and **2**=580 kWh/year (best Japanese model).

TABLE 2a: Net Energy Savings for Efficient Refrigerators in Spokane, WA. for Houses without Space Cooling									
House	Int Gain	Refrig erator	Heating Load	Heating Demand	Heating Season	Heating Net Savings		% Savings	% Savings
(a)	(b)	(c)	[kWh]	[% yr]	[days]	[kWh]	[%]	100-%year	% non-HS
TE	High	0	20920	55.9	251	-	-	-	-
TE	High	1	21080	56.1	252	110	40.7	0.92	1.30
TE	High	2	21270	56.4	252	220	38.6	0.88	1.24
TE	Low	0	22540	58.0	261	-	-	-	-
TE	Low	1	22720	58.3	262	90	33.3	0.79	1.17
TE	Low	2	22910	58.6	263	200	35.1	0.84	1.23
EE	High	0	11400	46.2	212	-	-	-	-
EE	High	1	11550	46.4	214	120	44.4	0.83	1.06
EE	High	2	11720	46.8	216	250	43.9	0.82	1.05
EE	Low	0	12840	48.8	227	-	-	-	-
EE	Low	1	13000	49.1	229	110	40.7	0.79	1.08
EE	Low	2	13180	49.4	230	230	40.4	0.79	1.07
TN	High	0	12280	47.2	217	-	-	-	-
TN	High	1	12430	47.6	218	120	44.4	0.84	1.10
TN	High	2	12600	47.8	220	250	43.9	0.83	1.08
TN	Low	0	13750	49.9	232	-	-	-	-
TN	Low	1	13910	50.3	233	110	40.7	0.81	1.12
TN	Low	2	14090	50.6	234	230	40.4	0.81	1.11
EN	High	0	4409	38.5	191	-	-	-	-
EN	High	1	4526	38.8	192	153	56.7	0.92	1.19
EN	High	2	4660	39.3	195	319	56.0	0.91	1.17
EN	Low	0	5592	42.1	207	-	-	-	-
EN	Low	1	5719	42.5	207	143	53.0	0.92	1.22
EN	Low	2	5867	43.1	208	295	51.8	0.89	1.20

(a) **TE**=Typical Existing, **EE**=Efficient Existing (i.e. weatherized), **TN**=Typical New, and **EN**=Efficient New (i.e., superinsulated MCS).

(b) **High**=nominal internal gain of 72 kBTU/day and **Low**=nominal internal gain of 48 kBTU/day.

(c) **0**=typical new refrigerator consumption of 1150 kWh/year, **1**=880 kWh/year (best US model) and **2**=580 kWh/year (best Japanese model).

TABLE 2b: Net Energy Savings for Efficient Refrigerators in Spokane, WA for Houses with Space Cooling

House	Int Gain	Refrig erator	Cooling Load	Cooling Demand	Cooling Season	Combined Net Savings		Decrease in season
(a)	(b)	(c)	[kWh]	[% yr]	[days]	[kWh]	[%]	[days]
TE	High	0	3684	14.1	63	-	-	-
TE	High	1	3623	13.9	62	140	52.0	1
TE	High	2	3554	13.7	60	285	50.0	3
TE	Low	0	3121	12.2	53	-	-	-
TE	Low	1	3064	12.1	51	118	43.9	2
TE	Low	2	3002	11.9	51	260	45.5	2
EE	High	0	4260	19.4	88	-	-	-
EE	High	1	4177	19.0	87	162	59.8	1
EE	High	2	4085	18.6	83	338	59.2	5
EE	Low	0	3503	16.4	74	-	-	-
EE	Low	1	3426	16.1	73	148	55.0	1
EE	Low	2	3343	15.8	72	310	54.4	2
TN	High	0	4172	18.7	85	-	-	-
TN	High	1	4092	18.4	82	160	59.3	3
TN	High	2	4004	18.1	82	334	58.6	3
TN	Low	0	3439	15.9	72	-	-	-
TN	Low	1	3365	15.7	71	147	54.4	1
TN	Low	2	3285	15.4	70	307	53.9	2
EN	High	0	4372	24.2	102	-	-	-
EN	High	1	4261	23.8	102	208	77.2	0
EN	High	2	4137	23.1	98	436	76.6	2
EN	Low	0	3381	19.7	81	-	-	-
EN	Low	1	3289	19.4	81	189	70.0	0
EN	Low	2	3183	18.7	78	394	69.1	3

(a) **TE**=Typical Existing, **EE**=Efficient Existing (i.e. weatherized), **TN**=Typical New, and **EN**=Efficient New (i.e., superinsulated MCS).

(b) **High**=nominal internal gain of 72 kBTU/day and **Low**=nominal internal gain of 48 kBTU/day.

(c) **0**=typical new refrigerator consumption of 1150 kWh/year, **1**=880 kWh/year (best US model) and **2**=580 kWh/year (best Japanese model).

TABLE 3a: Net Energy Savings for Efficient Refrigerators in Missoula, MT for Houses without Space Cooling

House (a)	Int Gain (b)	Refrigerator (c)	Heating Load [kWh]	Heating Demand [% yr]	Heating Season [days]	Heating Net Savings [kWh]	Heating Net Savings [%]	% Savings / 100-%year	% Savings / % non-HS
TE	High	0	23470	61.4	280	-	-	-	-
TE	High	1	23650	61.6	280	90	33.3	0.86	1.43
TE	High	2	23850	61.9	282	190	33.3	0.86	1.43
TE	Low	0	25250	63.6	291	-	-	-	-
TE	Low	1	25440	63.9	293	80	29.6	0.81	1.46
TE	Low	2	25650	64.1	294	170	29.8	0.82	1.47
EE	High	0	12650	51.3	229	-	-	-	-
EE	High	1	12810	51.7	231	110	40.7	0.84	1.09
EE	High	2	12990	52.1	233	230	40.4	0.83	1.08
EE	Low	0	14210	54.3	244	-	-	-	-
EE	Low	1	14390	54.7	246	90	33.3	0.73	1.00
EE	Low	2	14570	55.0	247	210	36.8	0.81	1.11
TN	High	0	13630	52.6	235	-	-	-	-
TN	High	1	13790	53.0	237	110	40.7	0.86	1.14
TN	High	2	13980	53.3	238	220	38.6	0.81	1.08
TN	Low	0	15220	55.5	249	-	-	-	-
TN	Low	1	15390	55.7	250	100	37.0	0.83	1.16
TN	Low	2	15590	56.1	252	200	35.1	0.79	1.10
EN	High	0	5169	43.0	206	-	-	-	-
EN	High	1	5297	43.5	208	142	52.6	0.92	1.21
EN	High	2	5446	43.9	208	293	51.4	0.90	1.18
EN	Low	0	6455	47.2	220	-	-	-	-
EN	Low	1	6600	47.6	222	125	46.3	0.88	1.17
EN	Low	2	6758	48.0	223	267	46.8	0.89	1.18

(a) **TE**=Typical Existing, **EE**=Efficient Existing (i.e. weatherized), **TN**=Typical New, and **EN**=Efficient New (i.e., superinsulated MCS).

(b) **High**=nominal internal gain of 72 kBTU/day and **Low**=nominal internal gain of 48 kBTU/day.

(c) **0**=typical new refrigerator consumption of 1150 kWh/year, **1**=880 kWh/year (best US model) and **2**=580 kWh/year (best Japanese model).

TABLE 3b: Net Energy Savings for Efficient Refrigerators in Missoula, MT for Houses with Space Cooling								
House	Int Gain	Refrig erator	Cooling Load	Cooling Demand	Cooling Season	Combined Net Savings		Decrease in season
(a)	(b)	(c)	[kWh]	[% yr]	[days]	[kWh]	[%]	[days]
TE	High	0	2801	10.4	43	-	-	-
TE	High	1	2685	10.2	43	115	42.4	0
TE	High	2	2699	10.2	43	241	42.3	0
TE	Low	0	2355	9.06	37	-	-	-
TE	Low	1	2311	8.90	36	102	37.8	1
TE	Low	2	2263	8.66	35	216	37.9	2
EE	High	0	3360	15.1	71	-	-	-
EE	High	1	3289	14.8	70	145	53.9	1
EE	High	2	3209	14.5	69	305	53.6	2
EE	Low	0	2703	12.4	59	-	-	-
EE	Low	1	2638	12.2	58	122	45.4	1
EE	Low	2	2568	12.0	56	277	48.7	3
TN	High	0	3273	14.4	68	-	-	-
TN	High	1	3204	14.2	67	144	53.5	1
TN	High	2	3127	13.9	65	293	51.4	3
TN	Low	0	2641	12.0	56	-	-	-
TN	Low	1	2578	11.7	55	131	48.7	1
TN	Low	2	2511	11.5	53	265	46.5	3
EN	High	0	3400	19.6	82	-	-	-
EN	High	1	3300	19.0	79	192	71.1	3
EN	High	2	3194	18.4	78	396	69.5	4
EN	Low	0	2552	15.6	66	-	-	-
EN	Low	1	2472	15.3	65	165	61.1	1
EN	Low	2	2382	14.9	64	352	61.8	2

(a) **TE**=Typical Existing, **EE**=Efficient Existing (i.e. weatherized), **TN**=Typical New, and **EN**=Efficient New (i.e., superinsulated MCS).

(b) **High**=nominal internal gain of 72 kBTU/day and **Low**=nominal internal gain of 48 kBTU/day.

(c) **0**=typical new refrigerator consumption of 1150 kWh/year, **1**=880 kWh/year (best US model) and **2**=580 kWh/year (best Japanese model).

To examine the impact of seasonal variations in refrigerator consumption, several sensitivity runs were performed. To model the increase in refrigerator consumption that occurs when the indoor temperature rises, it was assumed that the refrigerator would consume 25% more electricity during the non-heating season in a house without air conditioning. For each refrigerator, the consumption in the winter was reduced and the the summer consumption set equal to 1.25 times that value, so as to maintain the same annual consumption. The results of these simulations are compared with the constant consumption simulations in Table 4. The comparisons are made for a typical existing houses in Portland and Missoula, and are made for "high" internal gain conditions (21 kWh/day (72 kBtu/day)).

TABLE 4: Comparison of Net Energy Savings Obtained Assuming 25% Higher Refrigerator Consumption During the Non-Heating Season

Site (a)	Int Gain (b)	Refrig erator (c)	Heating Load [kWh]	Heating Demand [% yr]	Heating Season [days]	Heating Net Savings [kWh]	Heating Net Savings [%]	% Savings / 100-%year	% Savings / % non-HS
PL	Con	0	13370	51.3	244	-	-	-	-
PL	Var	0	13410	51.3	244	-	-	-	-
PL	Con	2	13710	51.9	247	230	40.4	0.83	1.22
PL	Var	2	13740	51.9	247	240	42.1	0.86	1.27
MS	Con	0	23470	61.4	280	-	-	-	-
MS	Var	0	23500	61.4	279	-	-	-	-
MS	Con	2	23850	61.9	282	190	33.3	0.86	1.43
MS	Var	2	23870	61.9	282	200	35.1	0.91	1.49

a) **PL**=Portland, OR, **MS**=Missoula, MT

b) **Con**=constant nominal internal gain of 21 kWh/day (72 kBTU/day) and **Var**=variable nominal internal gain of 21 kWh/day (72 kBTU/day), with refrigerator consumption during the non-heating season (121 days in Portland, 85 days in Missoula) 25% greater than during the heating season.

c) **0**=typical new refrigerator consumption of 1150 kWh/year, and **2**=580 kWh/year (best Japanese model).

DISCUSSION

There are some general trends that can be extracted from the results in Tables 1-3:

- The net energy savings (or equivalently, the fraction of gross savings) decreases as the length of the heating season increases; and conversely the net energy savings increases as the length of the cooling season increases. Therefore, better-insulated houses, which have shorter heating seasons (and longer cooling seasons under the present assumptions), will benefit more from energy efficient refrigerators. It should be noted that refrigerator performance in the typical new house, house **TN**, is very close to that in the existing house that had been weatherized, house **EE**, as they have very similar heating and cooling seasons.
- The amount of gross savings that an energy efficient refrigerator provides has very little effect on the net savings percentage. That is, if 50% of the gross savings is realized for one energy-efficient refrigerator in a particular building, 50% will be realized by any other efficient model in the same building.
- The level of internal gains has a significant effect on the net savings: the higher the internal gains (independent of the refrigerator) the higher the expected savings. In general, the results show approximately a five percentage point increase in fractional net savings for the higher internal gains assumption.
- Houses with air conditioning save more (10-20 percentage points) energy by using efficient refrigerators because these houses see a reduction in cooling load, whereas the houses without air conditioning realize this savings in the form of better comfort.
- The inclusion of seasonal variations in refrigerator consumption had a small effect on the net energy savings realized with those refrigerators. In both sensitivity runs, the seasonal variations in consumption improved the performance by approximately two percentage points.
- Because the length of heating or cooling season (in days) is so dependent on the details of building operation and weather patterns during the shoulder seasons, it is not as good an indicator of the impact of retrofits as is the percentage of yearly hours in which there is a heating or cooling load. This can be seen by examining the last two columns of the *a* tables. These two columns can be interpreted as indicators of the net savings based upon the two different measures of heating season length. The length of heating season indicator has a mean value of 1.16 with standard deviation of 9.5%, while the percentage yearly on-time has mean value of 0.84 with a standard deviation of 4.8%, implying that it is a more reliable indicator of the net savings.

- Because the net savings percentage for efficient refrigerators is independent of the particular model, it is the best indicator of the effectiveness of energy efficient refrigerators. Table 5 contains a summary of these numbers for this study.

TABLE 5: SUMMARY OF NET SAVINGS PERCENTAGES

House (a)	Int Gain (b)	Portland, OR w/o AC [%]	Portland, OR AC [%]	Spokane, WA w/o AC [%]	Spokane, WA AC [%]	Missoula, MT w/o AC [%]	Missoula, MT AC [%]
TE	HIGH	41	51	40	51	33	42
TE	LOW	36	45	34	44	30	38
EE	HIGH	51	66	44	60	41	54
EE	LOW	45	59	41	55	35	47
TN	HIGH	49	64	44	59	40	52
TN	LOW	44	57	41	54	36	48
EN	HIGH	57	76	56	77	52	70
EN	LOW	51	66	52	70	47	61

CONCLUSIONS

The average fractional savings for the 48 cases listed above is 0.50 with a standard deviation of 22%, indicating that for the houses considered in this report, energy-efficient refrigerators will only save half of their nominal energy savings. The spread of results is large, with poorly insulated houses with low internal gains saving as little as one-third the nominal savings; and well-insulated houses with large internal gains and central air conditioning realizing up to three quarters of the nominal savings. However, the variations in net savings can be tracked reasonably well from the percentage off-time of the heating system. It was found that the net savings was 0.84 times the percentage off-time of the heating system, with a standard deviation of only 5%.

As a final conclusion we should note the limitations of the results presented herein, and suggest some issues that could be addressed in the future. One major issue that was not addressed is the economic savings that can be achieved in houses that are not electric-resistance heated. The savings for these houses can be obtained from the increases in heating load in tables 1-3, together with heating system efficiencies and fuel costs. Also left unaddressed is the issue of time varying internal gains. This could be addressed by inserting daily internal gain profiles and seasonal variations into the simulations (which could be accomplished within the present framework).

(a) **TE**=Typical Existing, **EE**=Efficient Existing (i.e. weatherized), **TN**=Typical New, and **EN**=Efficient New (i.e., superinsulated MCS).

(b) **High**=nominal internal gain of 72 kBTU/day and **Low**=nominal internal gain of 48 kBTU/day.

ACKNOWLEDGEMENTS

This work was supported by the Bonneville Power Administration, Portland, Oregon, under contract No. DE-AI79-84BP16357, and by the Assistant Secretary for Conservation and Renewable Energy, of the U.S. Department of Energy, under contract No. DE-AC03-76SF00098.

REFERENCES

1. *1983 Northwest Conservation and Electric Power Plan*, Volume I, published by Northwest Power Planning Council, April 27, 1983, Page 10.12.

2. *TRNSYS Manual*, Solar Engineering Laboratory, University of Wisconsin, Madison, WI, Version 12.1, 1984.

3. *ASHRAE Handbook of Fundamentals*, 1977, page 25.27; and 1981, page 26.34.

4. *ASHRAE Handbook of Fundamentals*, Chapter 22, 1981.

5. M.H. Sherman, M.P. Modera, *Comparison of Predicted and Measured Infiltration Using the LBL Infiltration Model* (to be published in Standard Technical Publication of ASTM Conference on Air Infiltration, Philadelphia, PA, April, 1984), Lawrence Berkeley Laboratory Report, LBL-17001.

6. "Hourly Solar Radiation - Surface Meteorological Observations", Solmet Volume 2 - Final Report TD-9724, National Oceanographic and Atmospheric Administration, 1979.

7. *Super Good Cents Technical Design Specifications*, Bonneville Power Administration, Office of Conservation, December, 1984.

8. *1983 Northwest Conservation and Electric Power Plan*, Volume II, published by Northwest Power Planning Council, April 27, 1983, Appendix J.

APPENDIX: Detailed Assumptions

Source: Grant Vincent
Bonneville Power Administration
(12/24/84)

STANDARD ASSUMPTIONS FOR SINGLE FAMILY HOUSING

House Type:	Ranch-style, wood frame construction
Foundation:	Crawlspace
Stories:	One
Climate Zones:	1) Portland, OR 2) Spokane, WA 3) Missoula, MT

Dimensions:

Floor Area	- 125 m^2 (1350 ft^2)
Ceiling Area	- 125 m^2 (1350 ft^2)
Wall Area	- 94.2 m^2 (1014 ft^2)
Window Area	- 13.6 m^2 (146 ft^2) (assumed equally distributed on all four sides)
Door Area	- 3.7 m^2 (40 ft^2) (two doors, 20 ft^2 each)
Volume	- 306 m^3 (10,800 ft^3)

Thermal Mass (mCp): 7600 kJ/^{o}C (4000 BTU/^{o}F)

Internal Heat Gains (people and appliances):

14 kWh/day (48,000 BTU/day)	- Assumed by the Council for developing the Model Conservation Standards
21 kWh/day (72,000 BTU/day)	- Assumed by BPA for the Super Goods Cents Program

Conservation Assumptions:

CONSERVATION ASSUMPTIONS FOR SINGLE FAMILY HOMES IN THE PACIFIC NORTHWEST

Conservation Component	Typical Existing	Full Wx. Existing	Typical New	*MCS New (Superinsulated)*		
					Zone 1	Zone 2
Ceilings						
Nominal R-Value of Insulation	R-11	R-38	R-30	R-38	R-38	R-38
U-Value [Btu/h ft^2 ^{o}F]	0.092	0.036	0.041	0.036	0.036	0.036
Modified U-Value	0.083	0.036	0.040	0.036	0.036	0.036
Walls						
Nominal R-Value of Insulation	R-4	R-11	R-11	R-27	R-31	R-31
U-Value [Btu/h ft^2 ^{o}F]	0.124	0.083	0.083	0.042	0.038	0.038
Floors						
Nominal R-Value of Insulation	R-2	R-19	R-19	R-19	R-30	R-30
U-Value [Btu/h ft^2 ^{o}F]	0.165	0.046	0.046	0.046	0.034	0.034
Modified U-Value	0.116	0.041	0.041	0.041	0.031	0.031
Windows						
# Glazings	Mixed	1G+S,2G	2G	3G	3G	3G
U-Value [Btu/h ft^2 ^{o}F]	0.746	0.64	0.71	0.359	0.359	0.359
Doors						
Type	Wood	Wood	Wood	Metal	Metal	Metal
U-Value [Btu/h ft^2 ^{o}F]	0.46	0.46	0.46	0.16	0.16	0.16
Air-To-Air Ex.	No	No	No	Yes	Yes	Yes
Infiltration (ACH)						
Natural	0.7	0.6	0.6	0.31	0.1	0.1
Mechanical	0.0	0.0	0.0	0.29	0.5	0.5
Effective	0.7	0.6	0.6	0.4	0.25	0.25
Attic Ventilation						
Design (ACH)	6.0	12	12	12	12	12
Average (ACH)	3.0	6.0	6.0	6.0	6.0	6.0
Crawlsp. Ventilation						
Design (ACH)	3.0	6.0	6.0	6.0	6.0	6.0
Average (ACH)	1.5	3.0	3.0	3.0	3.0	3.0

1. Typical Existing home is based on the 1979/80 Regional Survey.
2. Typical New home is based on the 1980 Oregon Uniform Building Code.
3. U-Values for Ceilings, Walls, and Floors account for standard framing.
4. U-Values for Ceilings also assume 2% void areas (lighting fixtures, etc.).
5. Modified U-Values for Ceilings and Floors also account for attic and crawlspace ventilation ("Design" values).
6. Air-To-Air Heat Exchangers are assumed to have an efficiency of 0.70 (for calculating the "Effective" infiltration rate of the MCS homes).

ENERGY-EFFICIENT REFRIGERATOR ASSUMPTIONS

(A) The average energy consumption of new, top freezer, automatic defrost refrigerators sold in the United States is 1150 kWh/year. The average size of these models is 17 to 18 cubic feet (an adjusted volume of 20.39 cubic feet). (Ref. 1)

(B) The most energy-efficient 17 to 18 cubic foot U.S. model is rated at 880 kWh/year (270 kWh/year savings as compared to the U.S. average). (Ref. 2, Whirlpool ET17HKXM)

(C) The most energy-efficient 17 to 18 cubic foot Japanese model is estimated to use 580 kWh/year (570 kWh/year savings as compared to the U.S. average). This estimate is based on the National NR 433 (15.0 cubic feet, 456 kWh/year) and the Sanyo SR 457 FB (19.8 cubic feet, 696 kWh/year). (Ref. 3)

References:

1. *1983 Energy Consumption and Efficiency Data for Refrigerators, Refrigerator-Freezers and Freezers,* Association of Home Appliance Manufacturers, Revised July 1, 1984

2. *1984 Consumer Selection Guide for Refrigerators and Freezers,* Association of Home Appliance Manufacturers.

3. "Efficient Refrigerators in Japan: A Comparative Survey of American and Japanese Trends Toward Energy Conserving Refrigerators," David B. Goldstein, *Proceedings from the ACEEE 1984 Summer Study on Energy Efficiency in Buildings,* American Council for an Energy-Efficient Economy, August 1984.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720