INTERACTION OF APPLIANCE EFFICIENCY AND SPACE CONDITIONING LOADS: APPLICATION TO RESIDENTIAL ENERGY DEMAND PROJECTIONS

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ABSTRACT

"Waste heat" given off by refrigerators, water heaters, and other appliances has significant effects on space conditioning requirements, reducing heating and increasing air conditioning. The importance of these effects varies with such factors as climate, thermal integrity of the residence, heating fuel prices, and furnace and air conditioner efficiencies.

The most widely used energy demand simulation models have neglected this interaction between appliances and space conditioning. This neglect might be reasonable if appliance efficiencies were expected to remain constant, since the effect of waste heat on heating and air conditioning loads would also remain constant. However, due to increased electricity prices and/or efficiency standards, we expect substantial appliance efficiency improvements, reduced waste heat, and modified space conditioning loads. We need, then, to incorporate interaction between appliances and space conditioning into projections of energy demand and into estimates of impacts of such policy options as efficiency standards.

This paper describes the results of incorporating this interaction into a version of the Oak Ridge National Laboratory (ORNL) computer simulation model used by the Northwest Power Planning Council to project residential demand for electricity in the Pacific Northwest. Projections of total demand and estimated impacts of an illustrative appliance efficiency standard are compared with those generated by the unimproved version of the ORNL model.

Projections of total demand by the new model are not greatly different from those of the original. However, the new model produces estimates of savings from the illustrative appliance efficiency standard which are substantially less than the original model. Unique conditions of the Pacific Northwest, which make it impossible to use these results to draw conclusions for other regions, are described.

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INTRODUCTION

"Waste heat" given off by refrigerators, water heaters, and other appliances has significant effects on space conditioning requirements, reducing heating and increasing air conditioning. The importance of these effects varies with such factors as climate, thermal integrity of the residence, heating fuel prices, and furnace and air conditioner efficiencies.

The most widely used energy demand simulation models have neglected this interaction between appliances and space conditioning. This neglect would be reasonable if appliance efficiencies were expected to remain constant, since the effect of waste heat on heating and air conditioning loads would also remain constant. However, due to increased electricity prices and/or efficiency standards, we expect substantial appliance efficiency improvements, reduced waste heat, and modified space conditioning loads. We need, then, to incorporate interaction between appliances and space conditioning into projections of energy demand and into estimates of impacts of such policy options as efficiency standards.

This paper describes the results of incorporating this interaction into a version of the Oak Ridge National Laboratory (ORNL) computer simulation model used by the Northwest Power Planning Council to project residential demand for electricity in the Pacific Northwest (PNW). Projections of total demand and estimated impacts of an illustrative appliance efficiency standard are compared with those generated by the unimproved version of the ORNL model.

METHODOLOGY

Before we could incorporate the interaction of appliance energy use with heating and cooling requirements, we needed two things: 1) a load-simulation analysis of the interaction, given climate appropriate to our region, and 2) structural modifications to the ORNL model to reflect properly the interaction revealed by the load-simulation analysis.

The load-simulation analysis done by Palmiter and Kennedy[1] fulfills the first requirement, and was the original stimulus of our interest in the whole issue. This analysis is based on the fact that energy used by appliances is sooner or later converted to heat. To the extent that the heat is given off inside the heated space during the heating season, the "waste heat" or "internal gains" reduce the need for heat from heating equipment. To the extent that the heat is given off inside an air conditioned space during the air conditioning season, the internal gains increase the cooling required from the air conditioner.

Palmiter and Kennedy's analysis consisted of simulating the heating and cooling loads of houses of varying thermal integrities and solar characteristics, in four locations (climates),[2] assuming two levels of internal gains. By comparing the assumed change in internal gains to the resulting change in heating loads, other influences remaining the same, they estimated the fraction of internal gains which is useful. They called this fraction the "utility of internal gains" for heating. Similarly, by comparing the assumed change in internal gains to the resulting change in combined heating and cooling loads they obtained an estimate of the utility of internal gains for combined loads.[3]

Palmiter and Kennedy found that the utility of internal gains did not vary greatly among the three PNW locations. Utility of internal gains for heating varies more significantly with thermal integrity; it decreases as the thermal integrity of the house improves. Both of these patterns are consistent with the general principle that the internal gains from appliances are more or less constant throughout the year, and that their usefulness depends on the length of the heating season, rather than its severity.

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1/Larry Palmiter and Mike Kennedy, Annual Thermal Utility of Internal Gains, 8th National Passive Solar Conference, American Solar Energy Society, Santa Fe NM, September, 1983

2/Three of the locations, Portland, Spokane and Missoula, are in the PNW, and one, Albuquerque, is in the Southwest.

3/Since internal gains increase cooling loads and decrease heating loads, the utility for combined loads is less than the utility for heating loads.

Palmiter and Kennedy characterized the variation of utility of internal gains with thermal integrity as following a curve of specification:

$$F = A + B*Ln(Q)$$

where F = the heating (or combined heating and cooling) utility of internal gains
A,B = coefficients
Ln = the natural logarithm
Q = the annual heating load for the high internal gains case in kwh/sq.ft.

The coefficients of the three cities of the PNW did not vary greatly, and our forecasting model does not run climate zones separately, so the coefficients for Portland were used to represent the entire region. The values used for A and B are .3976 and .1126, respectively, for the heating utility curve, and .2933 and .1429, respectively, for the curve representing the utility of internal gains for combined heating and cooling loads.[4] In the range of Q values commonly observed in the PNW (roughly 7 to 12 kwh/sq.ft.) the value of F for heating utility ranges from .62 to .68. That is, 62% to 68% of waste heat from appliance use inside the heated space is useful.

Incorporating these results in the ORNL residential demand simulation model was fairly straightforward. While explicit estimates of total internal gains for our base (or any other) year are not available, it is reasonable to assume that current estimates of base year heating and cooling requirements implicitly include the effects of internal gains. Based on this assumption, we concentrated on each year's <u>changes</u> in internal gains, compared to the base year, and the resulting changes of heating and cooling loads. The modification to the model followed the pattern:

1. For each year, the change in internal gains from those of the base year 1979 was calculated. This was accomplished by using the current appliances' efficiencies and utilization levels to calculate their energy use, and comparing that use to the use

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4/The latter curve will be lower, of course (lower F). As pointed out earlier, internal gains reduce heating needs but increase cooling needs; as a result, the usefulness of internal gains for combined heating and cooling is less than for heating alone. In a warmer climate (e.g. Miami) the combined utility might even be negative.

of the base year appliances. The result is an estimate of the change (in Btu's) in use by appliances.

2. To estimate the change (in Btu's) in energy given off inside the heated or air conditioned space, appropriate fractions estimated by Palmiter and Kennedy[5] for each type of appliance were multiplied by the total change in appliance use.

3. Current levels of thermal integrity were used to calculate a utility of internal gains (F in the equation above).

4. This value of F, multiplied by the change in energy given off inside the space, generated the final change in heating and cooling loads resulting from the new stock of appliances.

Presently, consumers are largely unaware of the subtleties of the interaction between appliance use and space conditioning loads. They are, however, aware of their utility bills, and they will observe future utility bills which implicitly reflect the physical reality of this interaction. In the long run, therefore, we can expect to see them act "as though" they are aware of it as they make fuel and efficiency choices for new houses. Thus, the model was modified to include the new levels of heating and cooling loads not only in the final accounting of energy use, but also in the simulation of fuel and efficiency choice for new houses. As a result, the increase in heating loads resulting from more efficient appliances will cause an increase in energy use for heating, but this will be partially offset in the long run by the choice of more efficient houses.

Ideally, the choice of efficiency of appliances should also take the interaction between their energy use and space conditioning loads into account. In the PNW, where heating loads are generally much higher than air conditioning loads, the net effect of a decrease in appliance energy use is an increase in space conditioning loads. As a result, the net economic incentive to choose more efficient appliances is reduced by the interaction. A model which simulates this choice should reflect this reduced incentive. Unfortunately, the incentive to choose more efficient appliances is then partially dependent on the efficiency of space conditioning (which we have just made partially dependent on appliance efficiency).

This sort of mutual dependence of appliance efficiencies and space conditioning efficiencies suggests that the determination of

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5/op. cit.

these variables would best be done by an iterative process which converges to a set of values which are mutually consistent. Such a model would inevitably be significantly larger and slower than the current one; in any case, construction of such a model is a task well beyond the resources we could commit to this work. Even the development of a simplified approximation is difficult, and has not yet been completed. The results described here, therefore, are interim results based on the assumption that the fuel and efficiency choice for space conditioning takes the interaction between appliances and space conditioning into account, but appliance choice does not.

RESULTS

The projected 2002 energy use of the revised model was compared to that of the original model for four cases:

Case A. The PNW grows according to the Power Planning Council's Medium Low assumptions; except for building efficiency codes already in place in 1983, appliance and space conditioning energy use respond to energy prices only.

Case B. The same as Case A except for the imposition of appliance efficiency standards[6] on refrigerators, freezers and lighting.

Case C. The same as Case A except that, as a result of weatherization programs and efficiency standards for new structures, the thermal integrity of the building stock is significantly improved.

Case D. This case combines the appliance efficiency standards of Case B with the thermally-efficient building stock of Case C.

Tables I and II summarize the results of these comparisons. Table I presents projections of electricity use only, while Table II

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6/These standards are not based on any optimization criterion, such as minimized life-cycle cost, nor are they intended to represent significant savings of energy. The intent in setting the standards was to make it possible to examine the relative differences in savings as projected by the original and revised models.

shows projected totals of all fuels.[7] The two models' projections for Case A differ (Line 1) by 172.0 AMW of electricity and 10.81 trillion Btu's of all fuels (2.4% and 3.2%, respectively). This change is not a trivial one, but neither is it large compared to the overall level of uncertainty about the projections.[8]

The more interesting differences in the two models' projections result from the simulation of the effect of appliance efficiency standards on energy use. Case B results imply savings (Line 3) due to the standards of 20.4 AMW of electricity and 0.61 trillion Btu's of all fuels according to the original model. When the revised model is used, the effects of the standard drop to 12.2 AMW of electricity and 0.05 trillion Btu's of all fuels. These are reductions of 40% and 92%, respectively, in the estimates of savings due to the standard--enough to radically alter an evaluation of cost-effectiveness of the standards.[9]

Palmiter and Kennedy found that the utility of internal gains is sensitive to the thermal integrity of the building, the utility declining as the thermal integrity improves. This being so, a given change in appliance use would have a smaller secondary impact on space conditioning (and a smaller net effect on total energy use) as thermal integrity is improved. As a result, we would expect to find that the revised model's projections of energy use are closer to those of the original when thermal integrity is assumed to be improved. This

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7/For those unfamiliar with the units used in Table I, an average megawatt (AMW) is the electricity produced by a generator of 1000 kw capacity, running continuously for 1 year.

8/For example, using the Power Planning Council's Medium High set of economic and demographic assumptions, regarded as having the same likelihood of occurrence as the Medium Low, raises Case A projections by more than 1200 AMW and 35 trillion Btu's.

9/Electricity savings are included in the all fuels totals at the "end use" rate of conversion (1 kwh = 3412 Btu). A "primary energy" rate of conversion, including Btu's lost in generation and transmission of electricity (e.g. 1 kwh = 11,500 Btu) would increase the Case B savings estimates for all fuels to 2.05 trillion Btu's for the original model and 0.90 trillion Btu's for the revised model. Measured in primary energy, the revised model estimates all fuels savings due to the efficiency standard which are 56% less than the original model's estimate. Whether electricity is counted in "end use" or in "primary energy" terms, the reduction in savings estimated by the revised model is substantial.

Table I. Projected electricity use in PNW (2002, AMW).

	Appliances (both models)	Total (original model)	Total (revised model)	Difference Between Models
1. Case A (Price response)	5043.8	7192.6	7364.6	172.6
2. Case B (Appliance efficiency standards)	5023.4	7172.2	7352.4	180.2
3. Estimated Savings of Appliance Efficiency Standards (Case A - Case B)	20.4	20.4	12.2	- 8.2
4. Case C (Price response + tight houses)	5043.8	6497.3	6631.9	134.6
5. Case D (Appliance efficiency standards + tight houses)	5023.4	6476.9	6617.6	140.7
6. Estimated Savings of Appliance Efficiency Standards (Case C - Case D)	20.4	20.4	14.3	- 6.1
7. Estimated Savings of Tight Houses (Case A - Case C)		695.3	732.7	37.4

Table II. Projected energy use in PNW (2002, all fuels, 10^{12}Btu).

	Appliances (both models)	Total (original model)	Total (revised model)	Difference Between Models
1. Case A (Price response)	170.54	337.97	348.78	10.81
2. Case B (Appliance efficiency standards)	169.93	337.36	348.73	11.37
3. Estimated Savings of Appliance Efficiency Standards (Case A - Case B)	0.61	0.61	0.05	- 0.56
4. Case C (Price response + tight houses)	170.54	304.65	313.59	8.94
5. Case D (Appliance efficiency standards + tight houses)	169.93	304.04	313.34	9.30
6. Estimated Savings of Appliance Efficiency Standards (Case C - Case D)	0.61	0.61	0.25	- 0.36
7. Estimated Savings of Tight Houses (Case A - Case C)		33.32	35.19	1.87

expectation is realized, as demonstrated by a comparison of Case C projections with those of Case A: These cases differ by the assumption of greater thermal integrity in Case C, which reduces the difference between the original and revised models' projections to 134.6 AMW of electricity and 8.94 trillion Btu's of all fuels (compared to the differences of 172.0 AMW and 10.81 trillion Btu's mentioned above for Case A). A comparison of Case D differences with those of Case B shows similar relationships.

The savings projected by the two models to result from appliance efficiency standards are also more similar with improved thermal integrities (line 6), though the differences which remain are still significant. The original model projects unchanged savings of 20.4 AMW of electricity and 0.61 trillion Btu's of all fuels, while the revised model now projects savings of 14.3 AMW of electricity and 0.25 trillion Btu's of all fuels. These savings projections by the revised model are 30% and 59% less, respectively, than those of the original model--still enough to alter an evaluation of cost effectiveness of standards significantly.

Finally, if we compare the projections of Case A with those of Case C, (or alternatively, Case B and Case D) we can estimate the effect of identical programs to improve thermal integrity, other influences remaining the same (Line 7). Since the revised model projects space conditioning loads which are larger than those of the original model, we can expect that the revised model will project larger impacts from a given program to improve thermal integrity. The results in Tables I and II are consistent with this expectation. The energy savings of improved thermal integrity projected by the revised model are higher by 5.4% and 5.6% for electricity and all fuels, respectively.

CAVEATS AND CONCLUSIONS

The first and perhaps most important limitation of the work reported here is that it is based on climate data specific to the Pacific Northwest. The PNW has relatively long heating seasons, which increases the heating utility of internal gains, and most of the population of the region lives in a climate which has almost no air conditioning season, which decreases the cooling disutility of internal gains. An argument could be made that the secondary effects of appliance efficiency standards are more unfavorable in the PNW than any other region in the U.S. If data were available to carry out the exercise reported here for the state of Florida, for example, we might find that the revised model projects appliance standards as more attractive than the original model, since the standards' secondary benefits (reduced air conditioning loads) might more than outweigh their secondary costs (increased space heating loads).

A number of other circumstances of the PNW are unusual. It has lower electricity prices than any other region of the U.S. and some of the highest residential prices of natural gas, resulting in high saturations of electric heating. The thermal integrity of our electrically-heated houses has reflected low electricity prices. It's not clear how these circumstances influence the result of the work reported here, but they should further discourage any impulse to draw conclusions for other regions without careful consideration.

The estimations of savings due to appliance standards presented in this study are only to illustrate the differences between the original and revised models. The estimation of savings falls several steps short of being an evaluation of net benefits. To make such an evaluation, we would need, in addition to the estimates of savings, estimates of the cost of the more efficient appliances, prices of all fuels, and the social discount rate. In many utility service areas we would also need estimates of the distribution of savings between peak and off-peak demand periods, and the costs of serving loads in those periods. The changed savings projections made by the revised model would change the level of net benefits, of course, but without carrying out the rest of the net benefits evaluation we cannot know whether they are positive or negative.

Notwithstanding these caveats, useful conclusions can be drawn from this study. The most important of these is that analysis of programs or policies intended to improve appliance efficiencies should not ignore secondary impacts on space conditioning loads. Depending on climate, fuel prices, thermal integrities, and efficiency of heating and air conditioning equipment, these secondary impacts may reduce net projected energy savings of a program, they may leave savings essentially unchanged, or they may even increase savings. This work has shown that under at least one set of realistic circumstances, the incorporation of secondary impacts into the analysis is enough to reduce net projected energy savings quite significantly.

A necessary condition for the incorporation of the interaction of appliance energy use and space conditioning loads in analysis of conservation programs is the completion of more work like Palmiter and Kennedy's, for an appropriate number of climates. Their study was fundamental to this one, and it is hard to imagine how analysis of similar programs in other climates can be done properly without climate-specific studies like theirs.