CALIFORNIA
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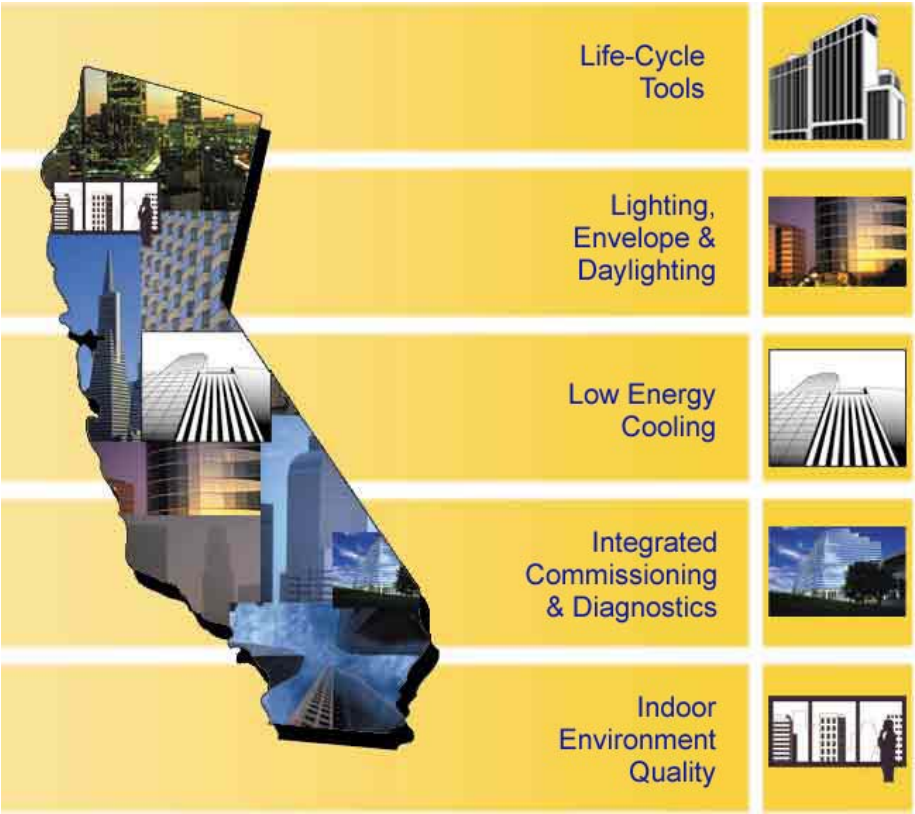
Retrofit Energy Savings Estimation Method



TECHNICAL REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Program's final report and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the High Performance Commercial Building Systems (HPCBS) Program. This Commercial Building Energy Benchmarking attachment provides supplemental information to the final report (Commission publication # 500-03-097-A2). The reports, and particularly the attachments, are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This document is the third of 22 technical attachments to the final report, and consists of software and a research report:

- RESEM-CA: Validation and Testing (E2P2.2T2b)
- RESEM-CA Software Download (E2P2.2T3)

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced this document as part of a multi-project programmatic contract (#400-99-012). The Buildings Program includes new and existing buildings in both the residential and the nonresidential sectors. The program seeks to decrease building energy use through research that will develop or improve energy-efficient technologies, strategies, tools, and building performance evaluation methods.

For the final report, other attachments or reports produced within this contract, or to obtain more information on the PIER Program, please visit http://www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. The reports and attachments are also available at the HPCBS website: http://buildings.lbl.gov/hpcbs/.

Abstracts

RESEM-CA Validation and Testing

This report documents the results of an extended comparison of RESEM-CA energy and economic performance predictions with the recognized benchmark tool DOE2.1E to determine the validity and effectiveness of this tool for retrofit design and analysis. The analysis was a two part comparison of patterns of (1) monthly and annual energy consumption of a simple base-case building and controlled variations in it to explore the predictions of load components of each program, and (2) a simplified life-cycle cost analysis of the predicted effects of selected Energy Conservation Measures (ECMs). The study tries to analyze and/or explain the differences that were observed.

On the whole, this validation study indicates that RESEM is a promising tool for retrofit analysis. As a result of this study some factors (incident solar radiation, outside air film coefficient, IR radiation) have been identified where there is a possibility of algorithmic improvements. These would have to be made in a way that does not without sacrifice the speed of the tool, necessary for extensive parametric search of optimum ECM measures.

RESEM-CA Software Download

The second item is the RESEM-CA software. The research on retrofit tools addresses the question: How do I know the retrofits proposed for my building are the most important ones from a life cycle cost perspective? Building owners and managers need to be confident that energy service companies (ESCOs) and other retrofit agents are working with standard techniques of assessment that adequately reflect California building types, equipment, weather, utility costs, and other issues.

The RESEM-CA software is available for download at:

http://eetd.lbl.gov/btp/resem.htm

California Energy Commission
Public Interest Energy Research Program

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(HPBCS E2P2.2T2b)

HPCBS

High Performance Commercial Building Systems

RESEM-CA
Validation and Testing
Element 2 - Life Cycle Tools
Project 2.2 - Retrofit Tools
Task 2

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1. Abstract

This report documents the results of an extended comparison of RESEM-CA energy and economic performance predictions with the recognized benchmark tool DOE2.1E to determine the validity and effectiveness of this tool for retrofit design and analysis. The analysis was a two part comparison of patterns of (1) monthly and annual energy consumption of a simple base-case building and controlled variations in it to explore the predictions of load components of each program, and (2) a simplified life-cycle cost analysis of the predicted effects of selected Energy Conservation Measures (ECMs). The study tries to analyze and/or explain the differences that were observed.

On the whole, this validation study indicates that RESEM is a promising tool for retrofit analysis. As a result of this study some factors (incident solar radiation, outside air film coefficient, IR radiation) have been identified where there is a possibility of algorithmic improvements. These would have to be made in a way that does not without sacrifice the speed of the tool, necessary for extensive parametric search of optimum ECM measures.

2. Introduction

This document is a part of the deliverable for Project 2.2 - Retrofit Tools, in the CEC-PIER High Performance Buildings Program. The objective of Project 2.2 is to deliver an updated and California-Customized retrofit analysis tool based on the earlier federally funded RESEM (Retrofit Energy Savings Estimation Method) tool [1]. Specific tasks to accomplish this were identified in Report # E2P2.2T1c, and addressed (a) modernization, (b) enhancement of basic analysis methods and capabilities, (c) adding, modifying, or updating databases for California building types, systems, components, utility rate structures, and weather.

This document documents the results of an extended comparison of simulation results of the core engine of the RESEM tool benchmarked against a widely accepted simulation tool, DOE2.1E [2]

RESEM is a fast, bin-method based simulation that involves some simplifications and approximations in its modeling algorithms. DOE-2.1E is a more detailed, slower, and more accurate sequential hourly analysis model. The speed of RESEM is necessary for extensive parametric searches for optimal packages of ECMs.

The validation and testing of RESEM algorithms was carried out in two phases:

1. Comparison of monthly heating and cooling loads, including peak heating and cooling loads, as computed by RESEM and DOE2.1E. The comparisons were performed on a simple base-case building with controlled variations in it to explore the predictions of load components of each program.
2. Comparison of the changes in electrical and gas energy consumption computed by RESEM and DOE2.1E, and a simple life-cycle cost difference based on them, when a selected list of ECMs was applied to a simple building design.

The latter comparison is very important because RESEM is a retrofit analysis tool and it is important to know how various ECM retrofit measures affect the energy and economic performance of the building. The following sections describe the results of each of these testing phases and analyzes the quality of agreement shown by the comparisons performed.

3. Validation of heating and cooling load computations

In this part of the analysis, the monthly loads are represented by electrical energy use for cooling and the monthly gas use for heating for convenience. They are computed by RESEM and DOE2.1E for a base case building and the results are compared directly. A very simple, single-zone base case building is used to validate the RESEM computations of heating and cooling loads. There are various factors (solar, conduction, convection, internal loads, etc.) contributing to the heating and cooling loads. Therefore, to isolate the effect of each individual factor, the base case building is further simplified in many instances to exclude certain heat gain/loss effects. For example, to study the effect of conduction gains and losses without the confounding effect of solar loads, the solar loads are "turned off" by setting the solar absorptance of the roof and walls to zero, and the shading coefficient of windows to zero. The base case building used in this series of tests is called the "Analytical Base Case" since it is used to analyze the various components of absolute differences between the predicted results of RESEM and DOE2.1E.

3.1. Analytical Base Case Building

The base case building is a single zone building. It has the following characteristics:

- 100 ft wide by 100 feet long oriented along the cardinal directions.
- Single floor with height = 10 ft.
- Wall U-value = 0.1 [Btu/hr*ft^2*F]
- Roof U-value = 0.05 [Btu/hr*ft^2*F]
- Solar absorptance of walls = 0.7, Solar absorptance of roof = 0.7
- 4 windows, one on each wall, with glazing area = 50% of wall area
- Single pane glazing, U-value = 1.1 [Btu/hr*ft^2*F], SC = 1.0.
- No internal loads, i.e. no people, lights, equipment loads.
- Building operation schedule = always "on"
- No infiltration loads.
- Heating set-point temperature = 72 F (occupied), 72 F (unoccupied).
- Cooling set-point temperature = 72 F (occupied), 72 F (unoccupied).
- Zone sensible loads only, i.e. Plant and System types = SUM (the heating and cooling load values will pass unchanged through the Plant and System load calculations).
- Weather file = Fresno, CA (Hot-dry), Los Angeles (coastal), Arcata (cold).

Appendix A includes the entire text of the input files for the Analytical Base Case, for both RESEM and DOE2.1E. Appendix C provides the entire list of the parametric analyses that were performed on the Analytical Base Case.

The building operation schedule was later changed so that the building was "on" from 7 am to 6 pm, and "off" the rest of the time. The same schedule is used for weekdays, Saturdays and Sundays. In RESEM some of the hourly load patterns are approximated as averages over operational hours and non-operational hours. While this is a reasonable assumption for most typical buildings, having a building that is always operational causes

a dampening of the daily load profile, with some of the cooling loads being pushed into nighttime hours and vice versa. Another version of RESEM will be explored where this averaging will either be avoided or will be carried out for smaller time-of-day periods. The analysis below is for the changed building schedule. All comparisons are for Fresno, CA, unless stated otherwise.

Figure 1gives the comparison between the cooling and heating loads computed by RESEM and DOE2.1E for the base case building. RESEM underestimates the annual cooling loads by 20% and overestimates the annual heating loads by 10% as compared with DOE2.1E. RESEM also shows a bigger monthly swing in heating and cooling loads as compared with DOE2.1E. Figure 2 shows the results for the Analytical Base Case building when internal loads and infiltration loads are added (details in input descriptions in Appendix B). In this case RESEM underestimates the annual cooling loads by 14% and overestimates the annual heating loads by 49% as compared with DOE2.1E. As we will see in the following sections, there are different components contributing to these differences. While conductive and internal load factors show very similar results for RESEM and DOE2.1E, solar and infiltration load factors are a big contributor to the differences seen in Figure 1 and Figure 2.

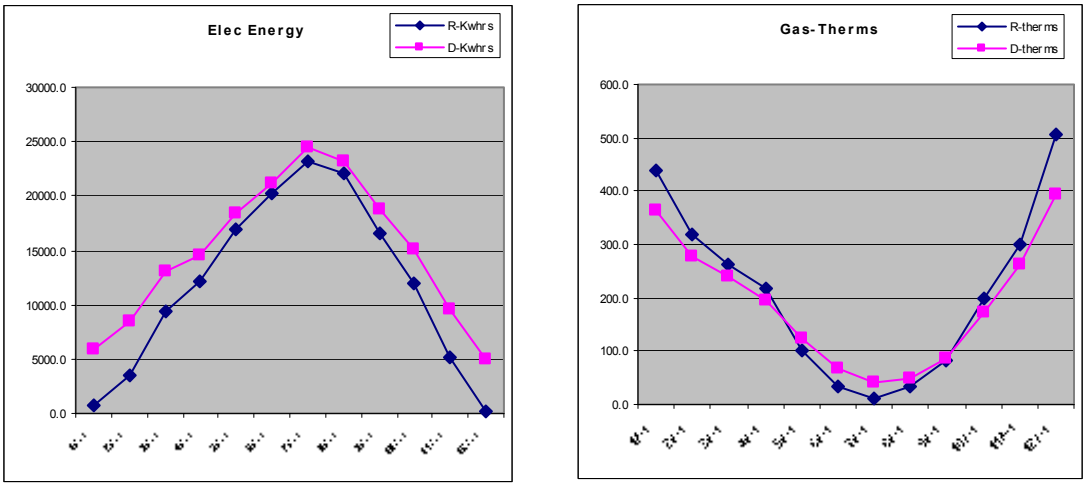


Figure 1:The cooling and heating loads as computed by RESEM and DOE2.1E in the base-case building.

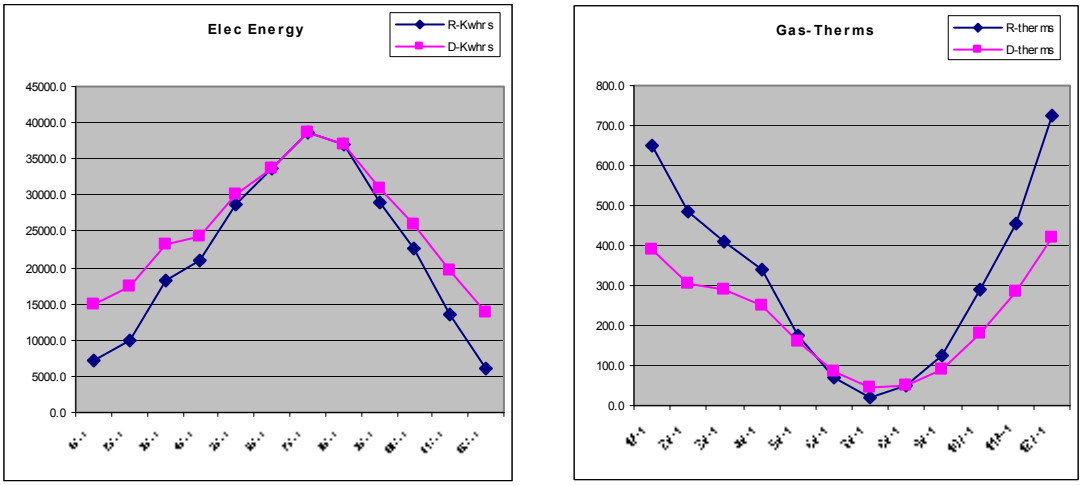


Figure 2: The cooling and heating loads as computed by RESEM and DOE2.1E in the base-case building with internal and infiltration loads included.

In the following analyses, we use graphs of monthly energy and gas consumption to visually compare the predicted results of RESEM and DOE2.1E. We observed that relative errors, RMS errors, and percentage differences tend to magnify small absolute differences between small numbers as compared with larger absolute differences between large numbers, and may be misleading sometimes. Also, the data set pertaining to any individual load factor is small enough to be compared visually. Therefore, the following analysis will have some subjectivity associated with visual comparison. However, all the files for generating this data (listed in Appendix C) are available with this report for possible future statistical analysis.

3.2. Conduction loads

The objective here is to compare the results of RESEM and DOE2.1E for calculation of steady-state heat transfer through the building envelope by conduction. Both programs use the basic formula $Q = U*A*\Delta T$ for the calculation of this heat transfer. However, there are differences in the calculation of the U-value, specifically the correction for the outside air film conductance. In RESEM, the user input for the U-value of a wall, roof, or window includes the film conductance. In DOE2.1E, the outside air film conductance changes with the wind-speed, air temperature, wind direction, surface roughness, surface temperature and surface emissivity. The film conductance also plays a role in the determination of the outside surface temperature in DOE2.1E. In RESEM, a constant value for the film conductance, based on information in the ASHRAE Handbook of Fundamentals [3], is used for the same purpose.

In this study we looked at the conduction loads with and without windows. We expect that the outside air film conductance will play a greater role when the overall resistance is small, as in windows. Figures 2 and 3 give the comparison for the simulation results of RESEM and DOE2.1E. The following changes were made to the base case to isolate the effect of conductive heat transfer:

- Solar absorptance of walls = 0.0, Solar absorptance of roof = 0.0
- In the case where windows are present, the shading coefficient (SC) = 0.
- The outside infrared (IR) emissivity for walls and roof = 0.0.

3.2.1. Conduction through walls and roof

We looked at the following cases:

- The base case building has only a roof, without any walls or windows (Figure 3).
- The base case building has all the walls and the roof, but no windows (Figure 4).

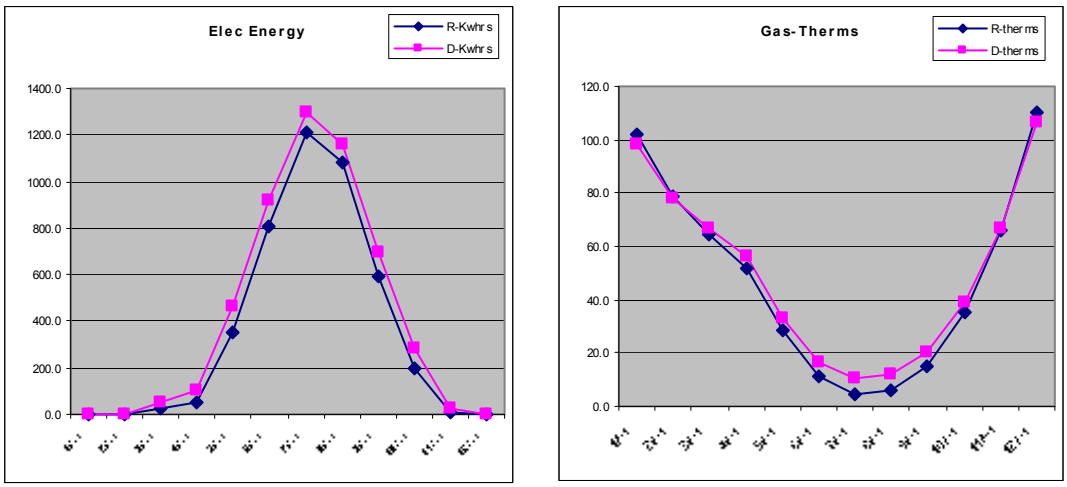


Figure 3: The cooling and heating loads due to conduction in the base-case building with only a roof.

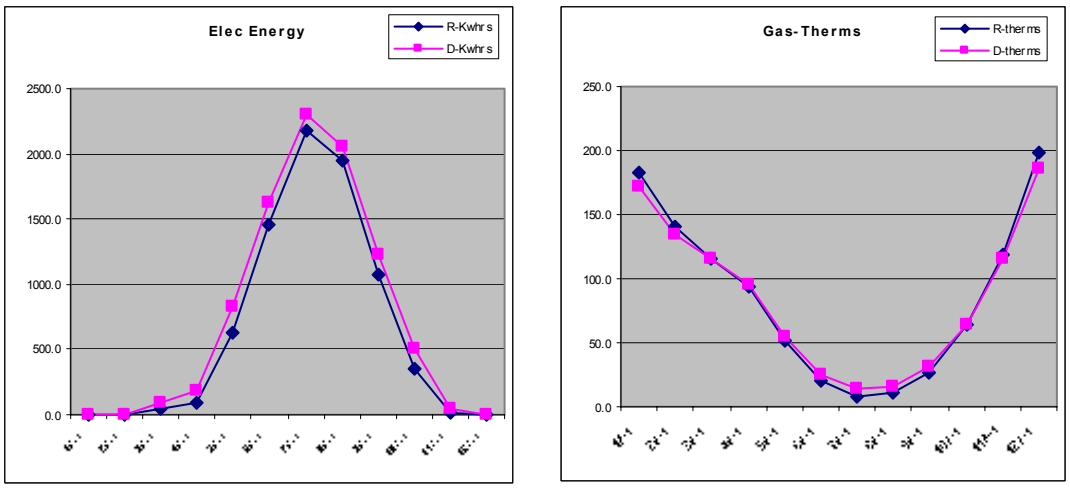


Figure 4: The cooling and heating loads due to conduction in the base-case building with walls and a roof.

The figures above show a good comparison between RESEM and DOE2.1E for conduction loads. RESEM underestimates the annual cooling loads by 12-13%, and the heating loads are within +/- 5% of DOE2 heating loads. RESEM shows a slightly lower

monthly swing in terms of cooling loads, and a slightly higher monthly swing in terms of heating loads. RESEM bins the weather data according to temperature intervals and time-of-day periods. Therefore, a table is generated where each row represents a time-of-day period and each column represents a particular temperature interval. The values in the table are the frequency of temperatures falling into that particular time-of-day period and temperature interval in any one month. The results given above suggest that this binning method contributes to speed and does not compromise the consideration of temperature in the cooling and heating load computations.

3.2.2. Conduction through windows

We looked at the following case:

- The base case building has only a window in the roof, without any opaque surface area (Figure 5).

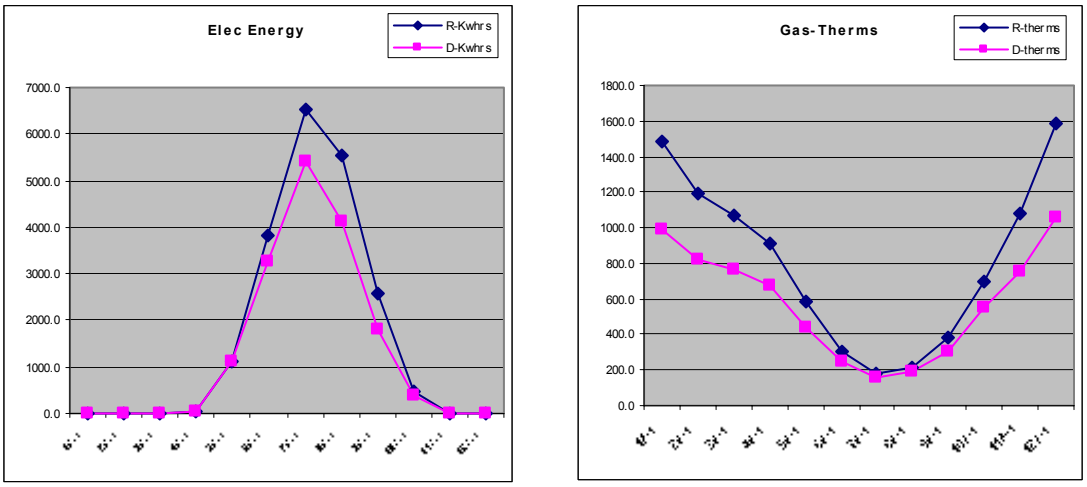


Figure 5: The cooling and heating loads due to conduction in the base-case building with only a roof window.

The comparison between RESEM and DOE2.1E results is not as good for conduction through windows. RESEM overestimates the annual cooling loads by 24% and overestimates the annual heating loads by 40%. This overestimation is particularly true under more extreme weather conditions, i.e. during summer for cooling and during winter for heating. This suggests that the inside and / or the outside film coefficient may be playing a part. The film conductance plays a bigger role in the case of low-resistance windows than in case of high-resistance walls and roof. This is probably why the differences in conduction loads are showing up in the case of windows, but not in the case of walls and roof. In this case, the infrared radiation (IR) is not turned off, and this may be another factor playing a part in the differences. However, since IR effects would tend to push the heating and cooling effects in opposite directions, contrary to what is evident here, the film conductance seems to be playing a bigger role here than IR.

3.3. Solar loads

In both RESEM and DOE2.1E there is solar heat gain when solar radiation is incident on walls, roofs, and windows. The incident solar radiation on walls and roofs is absorbed and conducted into the space. The incident solar radiation on windows is transmitted, absorbed and re-radiated, and conducted into the space. In both programs the incident solar radiation has two main components – direct radiation and diffuse radiation that depends on the weather conditions. Diffuse radiation can further be divided into the sky component and the ground-reflected component. These components depend upon the form factor, i.e. the view aspects, of the sky and the ground and are a geometric function of the wall/roof/window orientation and tilt.

There are two possible sources of differences in the two programs. Firstly, there are some differences in the algorithms used by RESEM and DOE2.1E in the calculation of solar gains. DOE2.1E uses the Perez model [Perez et. al, 1987] for the computation of diffuse radiation incident on tilted (i.e. non-horizontal) surfaces. In this model diffuse irradiance is adjusted for the sky brightness distribution. RESEM assumes a uniform sky and uses a geometric form factor to compute the diffuse irradiance from the sky. The second source for differences is the way in which transmittance through glazing is adjusted for the angle of incident radiation. DOE2.1E computes the angular transmittance in a couple of different ways, depending upon the glazing type. For the few glazing types that have been included in earlier versions of DOE2, the angular transmittance is calculated as a cubic polynomial in the cosine of the solar incidence angle. The values of the coefficients in this polynomial depend upon the glass type and number of panes. For the glazing library included with newer versions of DOE2, the angular transmittance is pre-calculated for various angles of incidence. In RESEM, the angular transmittance is taken as a function of angle of incidence alone. The Shading Coefficient (SC) is used to account for the glazing type.

In this study we looked at the solar loads due to solar absorptance and conduction through walls and solar transmittance through windows. Figure 6 and Figure 7 give the comparison for the simulation results of RESEM and DOE2.1E. The following changes were made to the base case to isolate the effect of solar loads:

- Outside surface IR emissivity for walls and roof = 0.
- In the case where windows are present, the U-value of windows = 0.0.

3.3.1. Solar radiation absorbed on wall and roof surfaces

We looked at the following cases:

- The base case building has only a roof, without any walls or windows (Figure 6).
- The base case building has all the walls and the roof, but no windows (Figure 7).

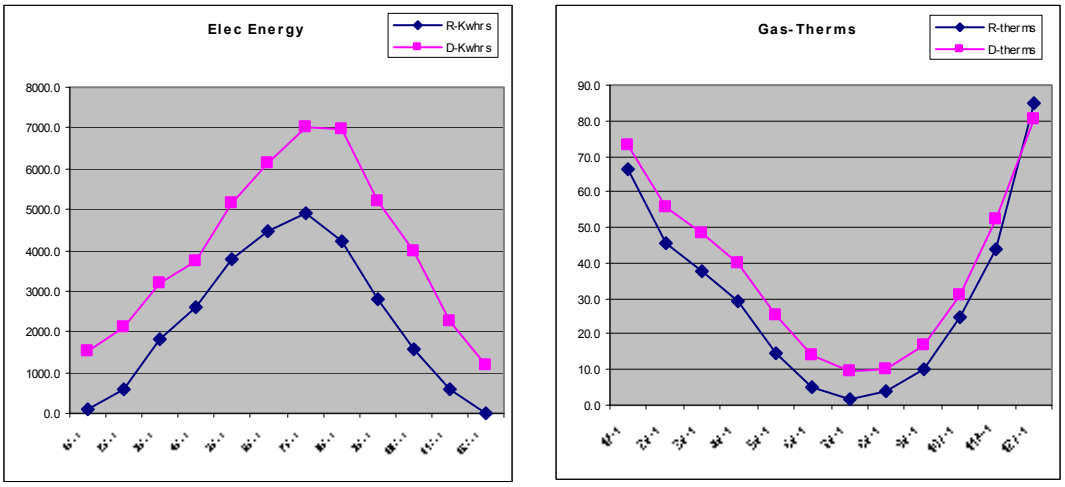


Figure 6: The cooling and heating loads due to solar gain in the base-case building with only a roof.

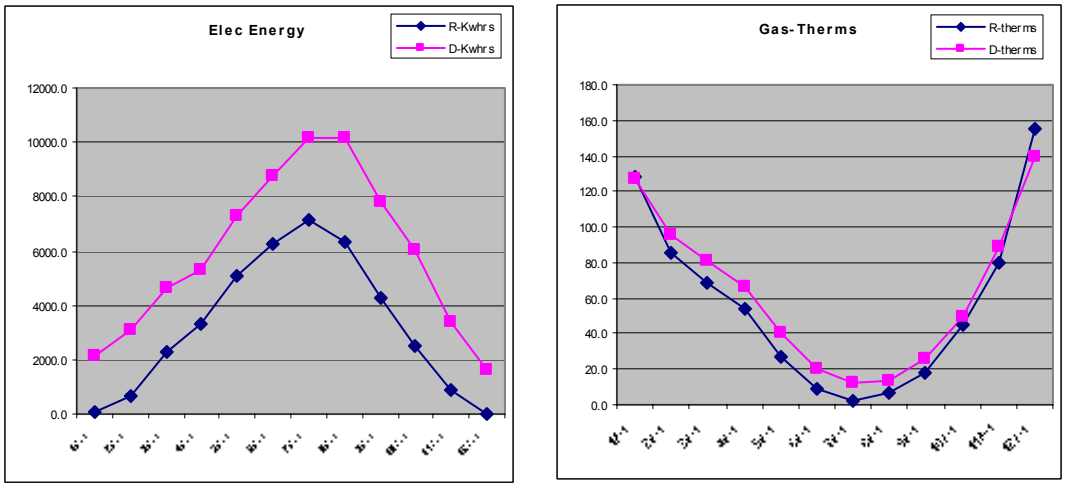


Figure 7: The cooling and heating loads due to solar gain in the base-case building with walls and a roof.

The figures above do not show a good agreement between RESEM and DOE2.1E results. RESEM underestimates the annual cooling loads by 43% and the annual heating loads by 19% in the roof-only case. It underestimates the annual cooling loads by 45% and the annual heating loads by 11% in the base case building with walls and a roof, but no windows. These results combine the effects of solar absorptance and conduction, but no IR emittance to the sky or solar transmission. Since we have already seen that there is

quite a good comparison between RESEM and DOE2.1E in terms of computation of conduction loads, and the algorithms for the computation of absorbed solar radiation are essentially the same for RESEM and DOE2.1E, most of this disparity may be due to differences in the computation of incident solar radiation. This includes the computation of the direct and diffuse components of solar radiation. (In the case of the horizontal roof, there is no ground reflected component.)

3.3.2. Solar radiation transmitted through windows

We looked at the following case:

- The base case building has only a window in the roof, without any opaque surface area (Figure 8).

In looking at the solar gains through the roof-window, the conduction gains/losses are factored out by setting the U-value of the window to zero. Therefore, only the effect of incident solar radiation and solar transmittance is considered here. Figure 8 does not show a very good comparison between RESEM and DOE2.1E results. RESEM underestimates the annual cooling loads by 21%. The heating loads are negligible or non-existent because there are no conduction losses, both in RESEM and DOE2.1E. The small heating loads that appear in the DOE2.1E results probably result from the boiler pilot consumption. As in the case of solar gain though walls and the roof, the disparity here may be due to differences in the computation of incident solar radiation, including the computation of the direct and diffuse components of solar radiation. In addition some of the disparity may be due to differences in the algorithms for the computation of transmitted radiation. Figure 9 shows that there is little difference between the angular transmittance values computed by the cubic polynomial in DOE2 and the RESEM algorithm for angles of incidence that are less than or equal to 60 degrees, but there are some differences at higher angles of incidence.

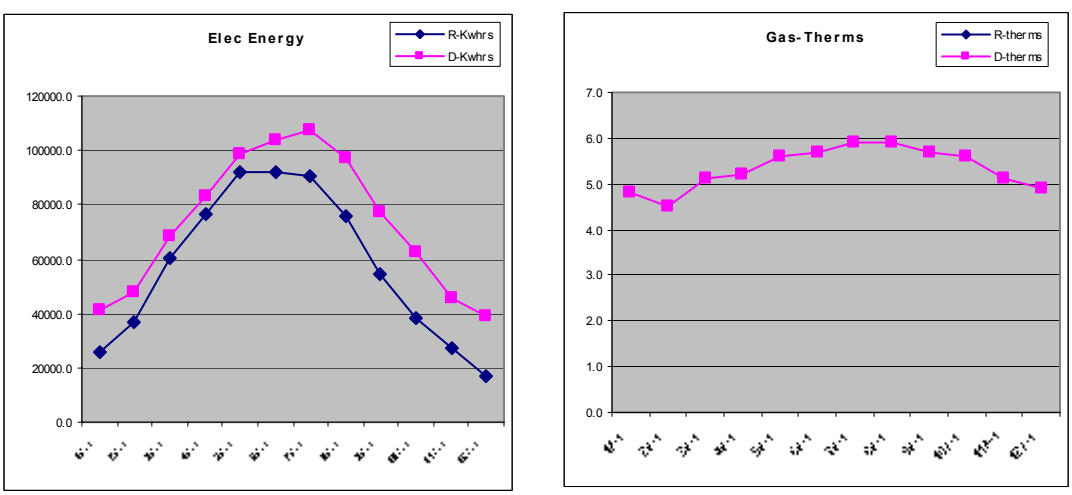


Figure 8: The cooling and heating loads due to solar transmission in the base-case building with only a roof window.

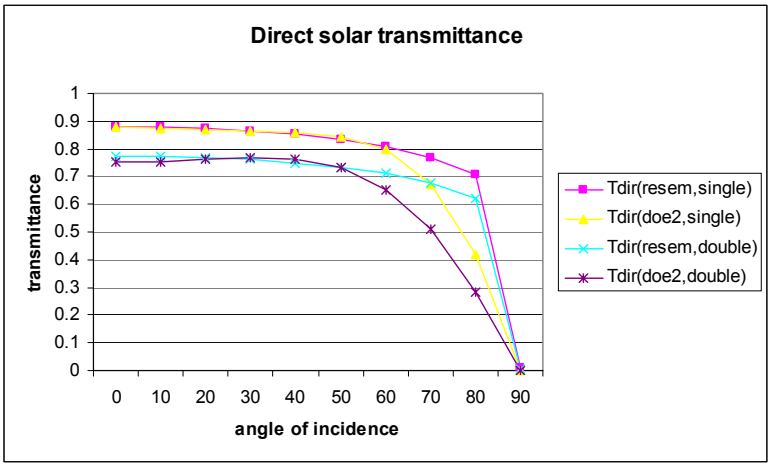


Figure 9: The direct solar transmittance through single clear and double clear glazing, as computed by DOE2.1E and RESEM.

3.4. IR radiation loss

There are differences in the way the infrared (IR) radiation loss to the sky is computed in RESEM and in DOE2.1E. RESEM assumes a constant factor for the IR loss according to [ASHRAE reference], modified by the surface emissivity. In DOE2.1E, the IR loss is computed according to the surface emissivity, the outside surface temperature, and the sky temperature. The sky temperature, in turn, is a function of the dew-point temperature, the air temperature, and the cloud cover. Both RESEM and DOE2.1E modify the IR loss to the sky by the view factor of the sky, i.e. the proportion of the sky that is visible for any given surface at a particular orientation and tilt angle.

In this study we looked at the effect of IR radiation exchange with the sky for a roof surface alone, and for a building with all walls and a roof but no windows. The results include conduction loads but making the following changes to the base case factored the effect of solar radiation out:

- Solar absorptance of walls and roof = 0.

We looked at the following cases:

- The base case building has only a roof, without any walls or windows (Figure 9).
- The base case building has all the walls and the roof, but no windows (Figure 10).

Figure 10 and Figure 11 give the comparison for the simulation results of RESEM and DOE2.1E. They show a reasonable comparison between the RESEM and DOE2.1E results. RESEM underestimates the annual cooling loads by 13% in the roof-only case, and by 16% in the case of all walls and a roof. RESEM also underestimates the annual heating loads in the roof-only case by 6%. In both cases, RESEM also shows a bigger swing in monthly loads for both heating and cooling. Therefore, RESEM underestimates both the cooling loads and the heating loads more in summer than in winter. This could

be combined effect of differences in the computation of the outside film coefficient (and therefore, conduction loads), as well as differences in the computation of the IR radiative exchange with the sky. However, since IR effects would tend to push the heating and cooling effects in opposite directions, contrary to what is evident here, the film conductance seems to be playing a bigger role here than IR. Also, since DOE2.1E is accounting for the seasonal effects of cloudiness and ambient/surface temperatures in the calculation of IR loss, and RESEM isn't, this could be contributing to the seasonal divergence in the results of DOE2.1E and RESEM.

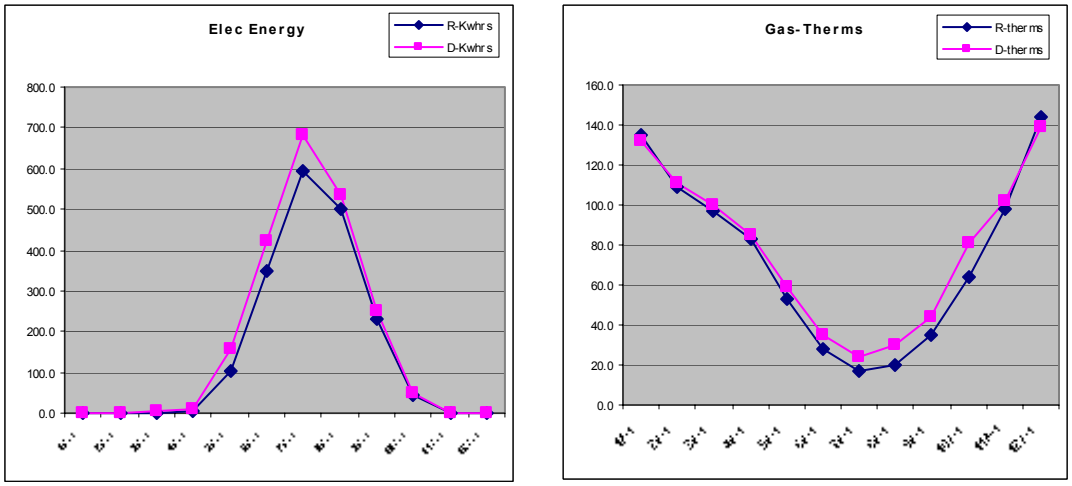


Figure 10: The cooling and heating loads with IR radiation to the sky in the base-case building with only a roof.

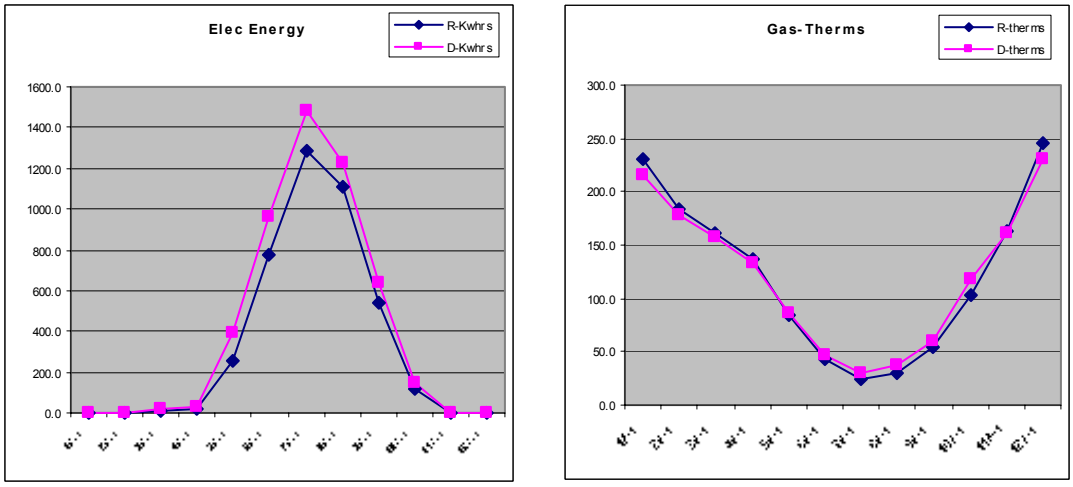


Figure 11: The cooling and heating loads with IR radiation to the sky in the base-case building with walls and a roof.

3.5. Internal loads

People (i.e. occupancy), equipment and lights contribute to the internal loads in terms of cooling and heating requirements of a zone. In addition, equipment and lights contribute

directly to electrical usage. Both RESEM and DOE2.1E model these internal loads with schedules defining hourly and monthly patterns of use/occupancy. Both programs allow the users to specify the sensible and latent portions of these loads, and the fractions that are added to the zone or exhausted to the outside.

Additional sources for internal loads, such as process heat and domestic hot water can be modeled in both programs, but were not modeled in this analysis. In this section of the study we looked at the effect of adding electric lights to the base case building. The following changes were made to the analytical base case building to model electric lighting:

- Installed lighting watts = 1.5 W/sq.ft.
- All the heat from the lights is added to the space.
- The lights are on at full power from 7 am to 6 pm everyday, including Saturday and Sunday.

Figure 12 gives the comparison for the simulation results of RESEM and DOE2.1E.

The results show that, with the addition of electric lights, in the case of both RESEM and DOE2 the cooling/electrical loads increase significantly (by 47% with RESEM and 42% with DOE2.1E) from the base case. Similarly, there is a reduction in heating loads (7% with RESEM and 14% with DOE2.1E) because the heat from the lights offsets some of the heating loads. The pattern of differences between RESEM and DOE2.1E simulation results does not change much with the addition of lights. This can be seen by comparing Figure 1 with Figure 12. This indicates that there is good correspondence between the modeling of electric lighting loads in RESEM and in DOE2.1E. This is confirmed in Figure 13 where all loads except for electric lighting loads are factored out. To factor out the effect of electric lighting alone, we made the following changes to the base case building:

- U-value of walls and roof = 0.0
- U-value of windows = 0.
- SC of windows = 0.

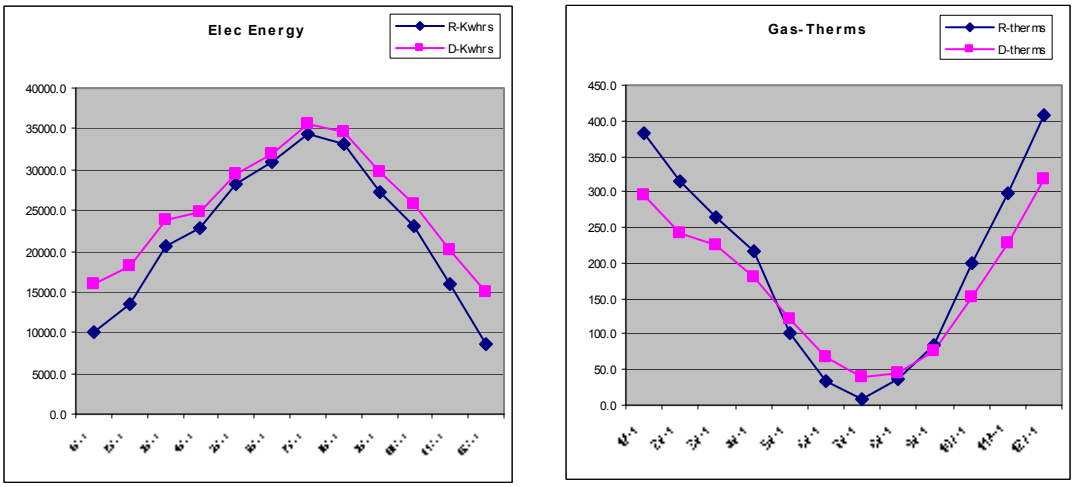


Figure 12: The cooling and heating loads with electric lights in the base-case building.

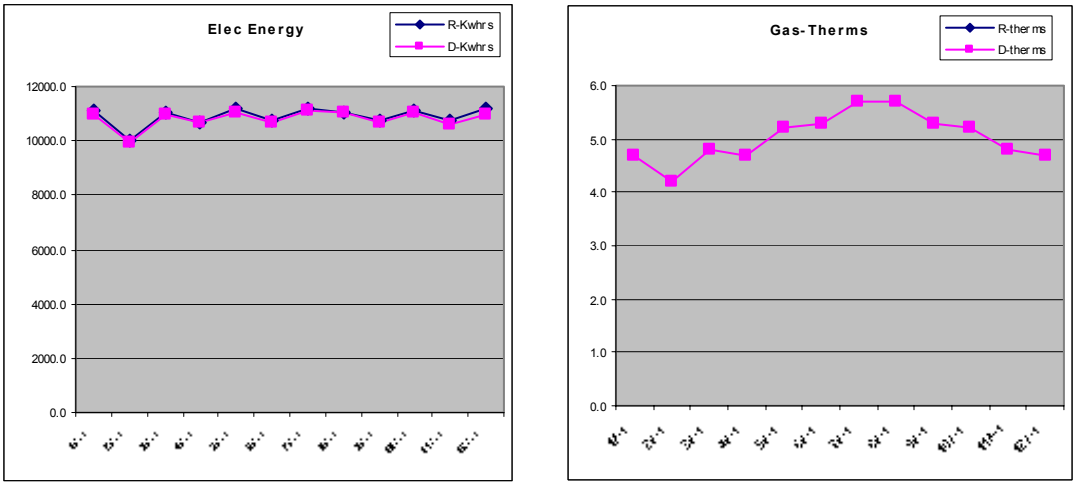


Figure 13: The cooling and heating loads with only electric lights and no other loads in the base-case building.

3.6. Infiltration loads

Infiltration impacts the heating and cooling loads by replacing conditioned inside air with unconditioned outside air, which then needs to be cooled or heated depending upon the outdoor temperature conditions. RESEM computes the volumetric airflow rate from the air-changes/hour given as an input, and subsequently the cooling or heating load from the temperature difference between inside and outside. DOE2.1E performs the same calculations if we specify the infiltration method to be the "Air-Change" method, but it modifies that value with a linear wind speed correction factor.

The Figure 14 shows the differences in the RESEM and DOE2.1E results when there is infiltration in the base case building. The following changes were made to the base case building to simulate the effect of infiltration:

- Air-Change/hour = 1.0, for unoccupied and occupied times of the day.

RESEM underestimates the annual cooling load by 21% and overestimates the annual heating load by 44% as compared with DOE2.1E. RESEM also shows a bigger seasonal swing in cooling and heating loads as compared with DOE2.1E. This is apparent in the base case when there is no infiltration, but this effect is exaggerated with infiltration. This may be because the seasonal changes in wind speed, and therefore infiltration rates are accounted for in DOE2.1E but not in RESEM. To factor out the effect of infiltration alone, we made the following changes to the base case building and looked at the results again:

- Air-Change/hour = 1.0, for unoccupied and occupied times of the day.
- U-value of walls and roof = 0.0
- No windows.

The results, shown in Figure 15, indicate that RESEM overestimates the cooling loads in summer and the heating loads in winter. This implies that RESEM is overestimating the airflow rate with infiltration because of the algorithmic differences, and therefore the heat transfer between the inside and outside.

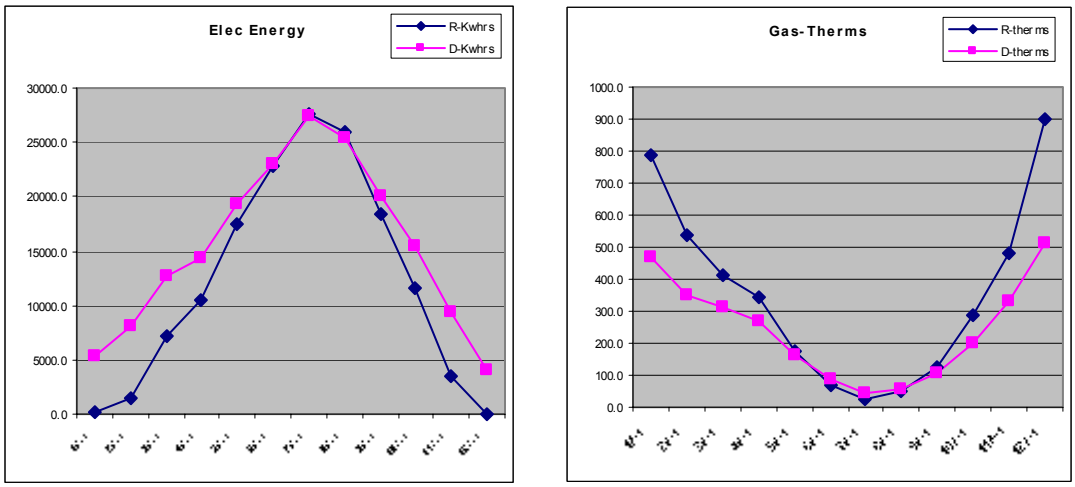


Figure 14: The cooling and heating loads with infiltration in the base-case building.

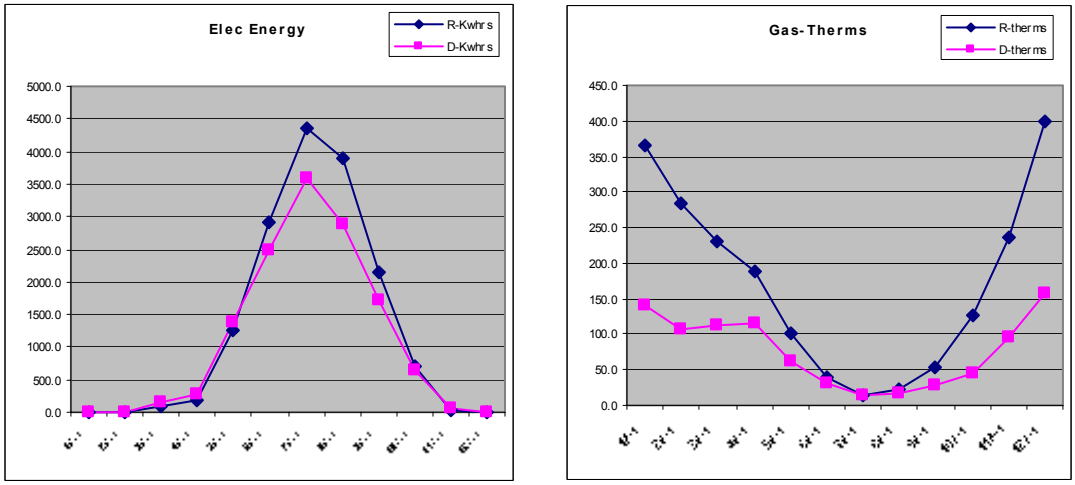


Figure 15: The cooling and heating loads with infiltration in the base-case building, with conduction and solar loads factored out.

3.7. Effect of orientation

The orientation of walls and windows will affect the annual and monthly cooling and heating loads for the building because of the spatial and temporal patterns of diffuse and direct solar radiation. In this section we look at two aspects of orientation:

- The monthly cooling and heating loads for each orientation with RESEM and DOE2.1E.
- How annual cooling and heating loads vary with orientation for RESEM and DOE2.1E.

The effect of orientation is considered both for walls and windows. The following changes are made to the base case building to consider the effect of orientation:

- In the case of considering the effect of wall orientation, the roof and all walls except for one (facing either south, east, north or west) are removed. There are no windows.
- In the case of considering the effect of window orientation, all walls and the roof are removed. All windows except for one (facing either south, east, north or west) are removed.

3.7.1. Orientation of walls

We looked at the following cases:

- The base case building has only one wall facing south, east, west, or north. The solar absorptance = 0.7, IR radiation = 0.9. (Figure 16, Figure 17, Figure 18, Figure 22)
- The base case building has only one wall facing south, east, west, or north. The solar absorptance = 0.7, IR radiation = 0. (Figure 19, Figure 20, Figure 21, Figure 23)

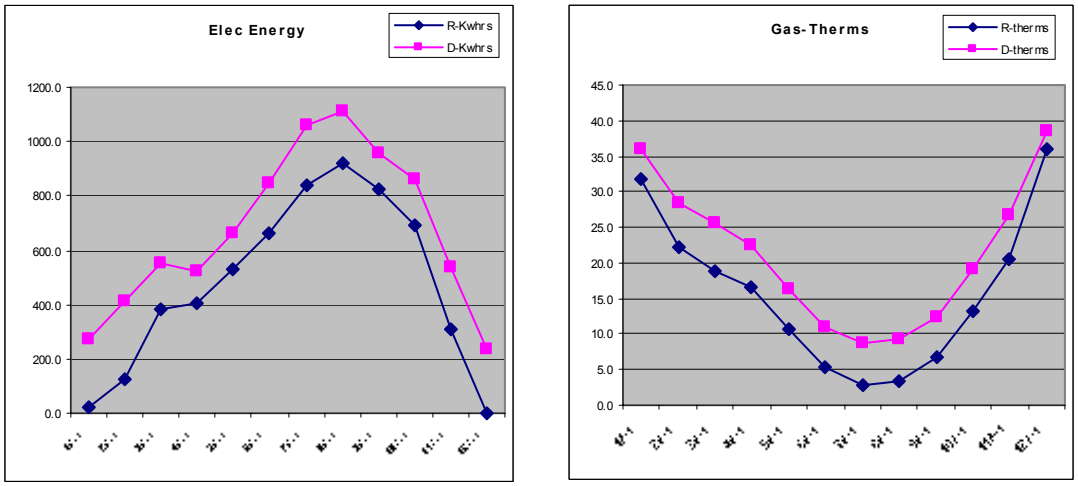


Figure 16: Cooling and heating loads with a south-facing wall, with solar absorptance and IR.

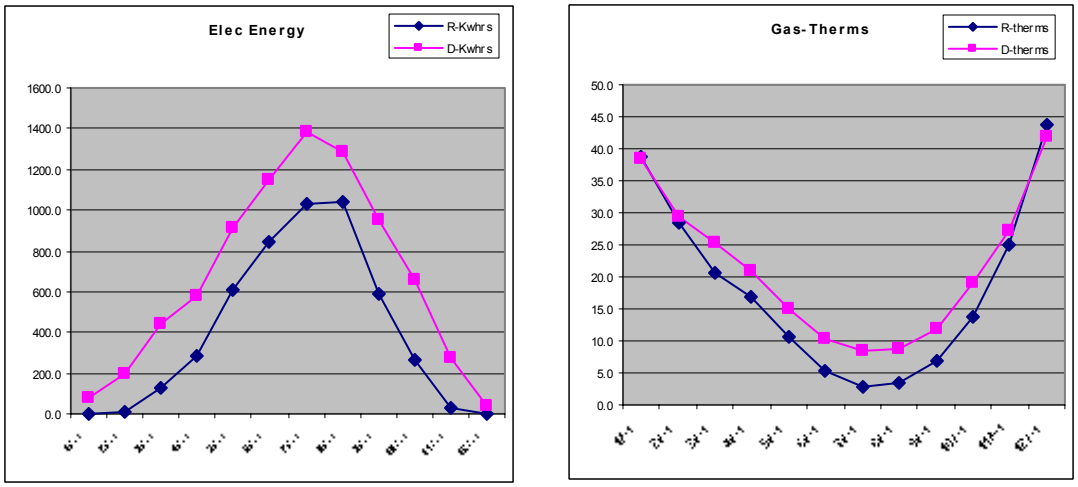


Figure 17: Cooling and heating loads with an east-facing wall, with solar absorptance and IR.

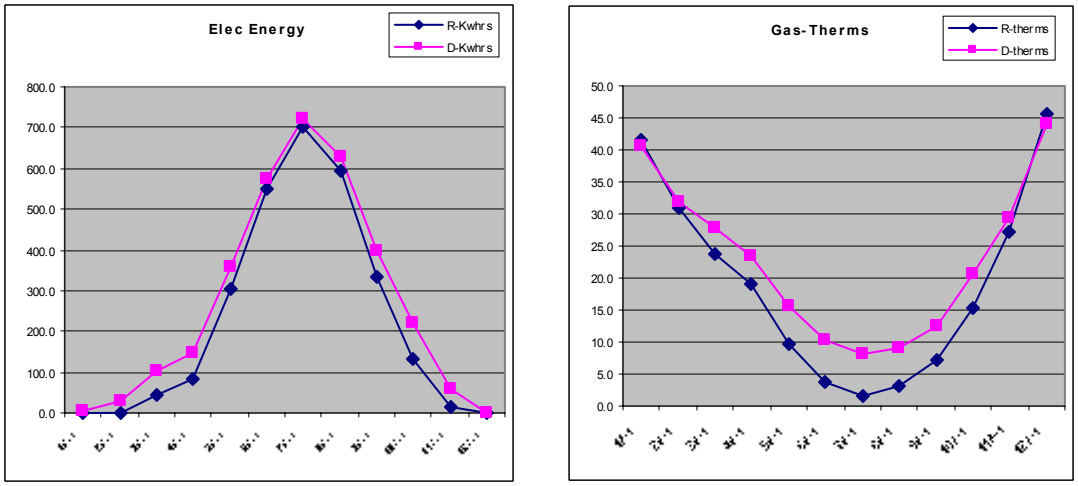


Figure 18: Cooling and heating loads with a north-facing wall, with solar absorptance and IR.

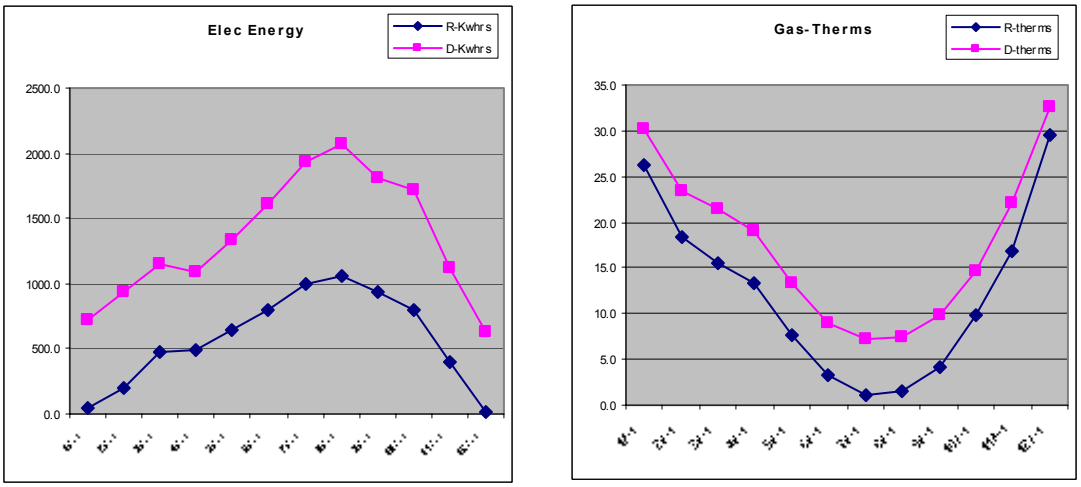


Figure 19: Cooling and heating loads with a south-facing wall, with solar absorptance but no IR.

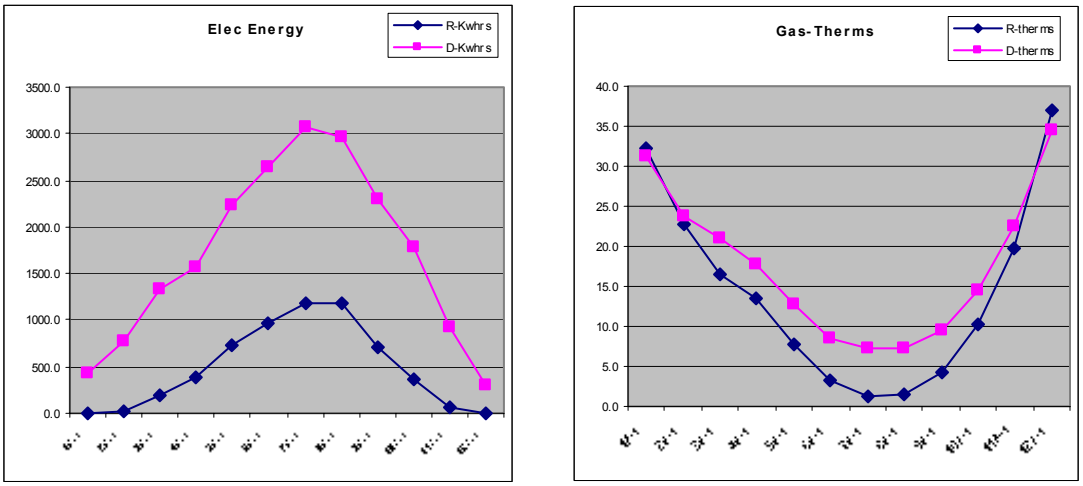


Figure 20: Cooling and heating loads with an east-facing wall, with solar absorptance but no IR.

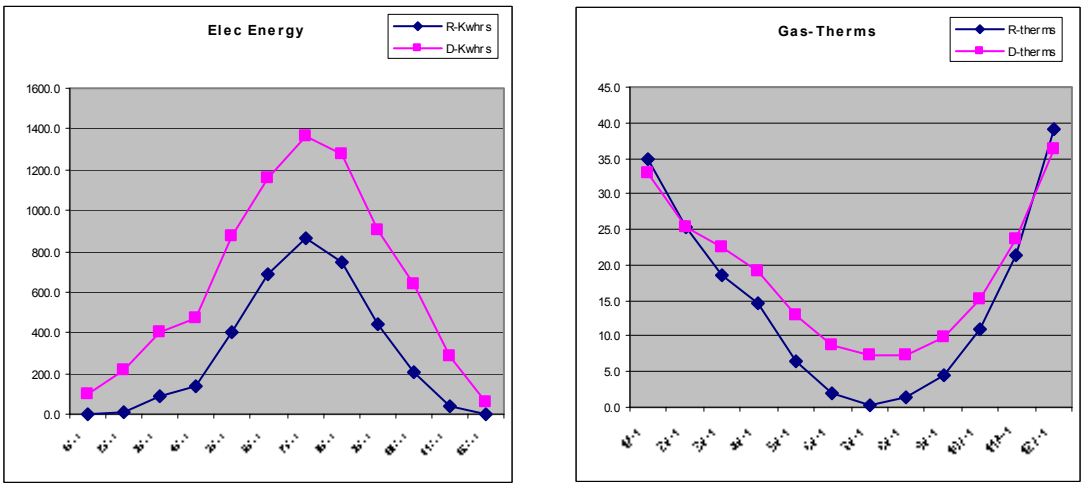


Figure 21: Cooling and heating loads with a north-facing wall, with solar absorptance but no IR.

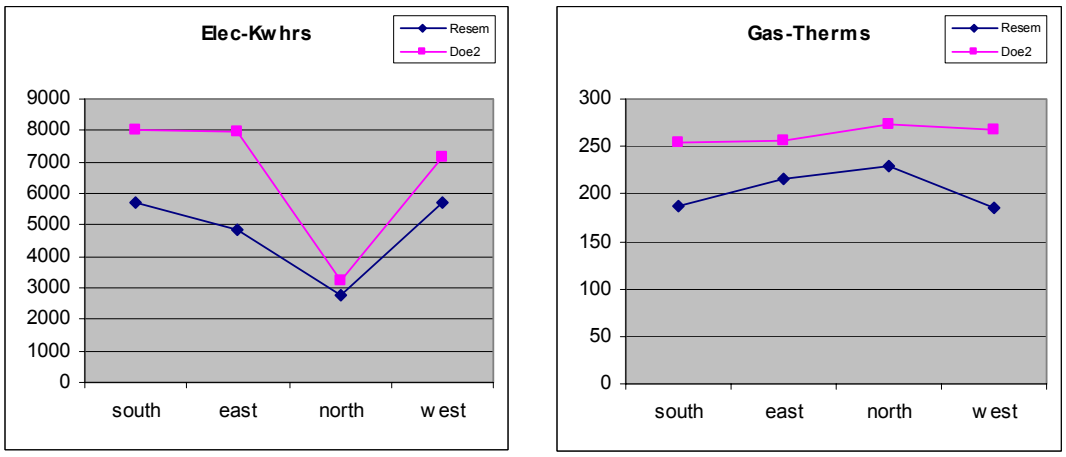


Figure 22: Change in cooling and heating loads with orientation, with solar absorptance and IR.

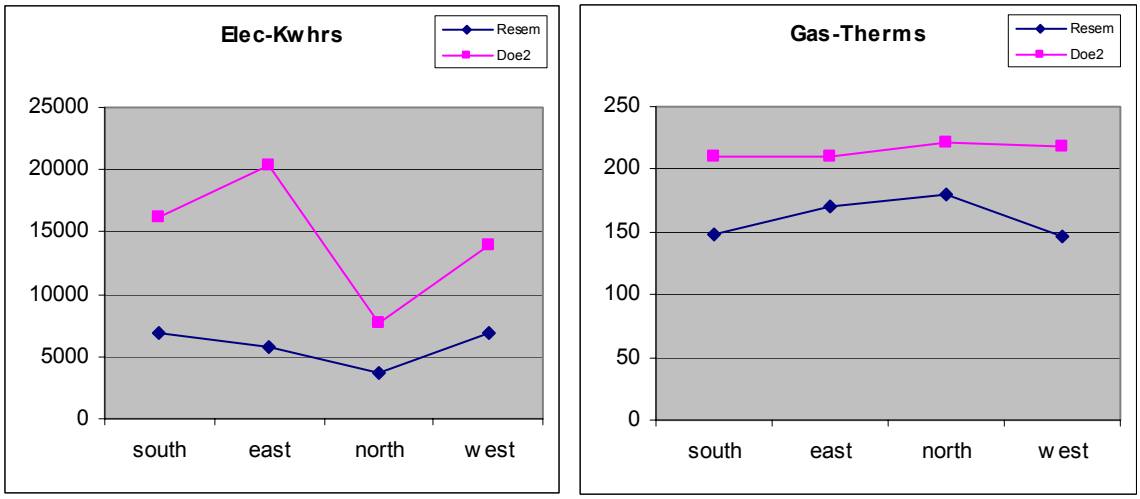


Figure 23: Change in cooling and heating loads with orientation, with solar absorptance but no IR.

The results indicate that differences between RESEM and DOE2.1E computations for monthly cooling loads are smaller when there is less direct solar radiation, i.e. during the winter months on the east and north. The differences are larger during the summer months on the east and south. This is particularly true when we factor out the effect of IR radiation by setting the surface emissivity to zero. On the south, the absolute differences between RESEM and DOE2.1E computations for cooling loads do not vary by month, maybe because the south facade sees the sun for the major part of the day all year around, even during winter months.

The differences in the heating loads computed by RESEM and DOE2.1E are smaller for the north and east facing walls as compared to the south-facing wall, especially during the winter months. RESEM is underestimating the heating loads, especially in summer on most facades, and all year around for the south facade. It is not very clear why the heating loads are underestimated at the same time as the cooling loads are underestimated. This may be an effect of averaging over time-of-day periods in RESEM, which dampens the modulation in solar loads.

The results shown in Figure 22 and Figure 23 indicate that both RESEM and DOE2.1E tend to follow the same pattern in how the cooling and heating loads change with orientation. However, DOE2.1E shows larger changes with orientation for cooling loads and smaller changes with orientation for heating loads as compared with RESEM.

3.7.2. Orientation of windows

To isolate the effect of solar radiation with respect to orientation, we looked at the following case:

- The base case building has no walls or roof. It has one window facing either south, east, north or west. The SC = 1.0 (single, clear glazing), U-value = 0.0. (Figures 24-28)

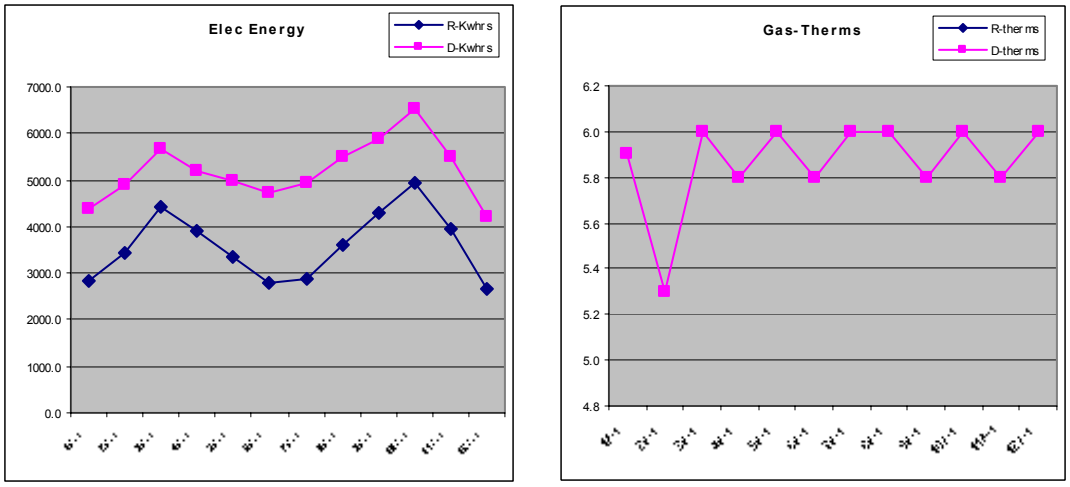


Figure 24: Cooling and heating loads with a south-facing window.

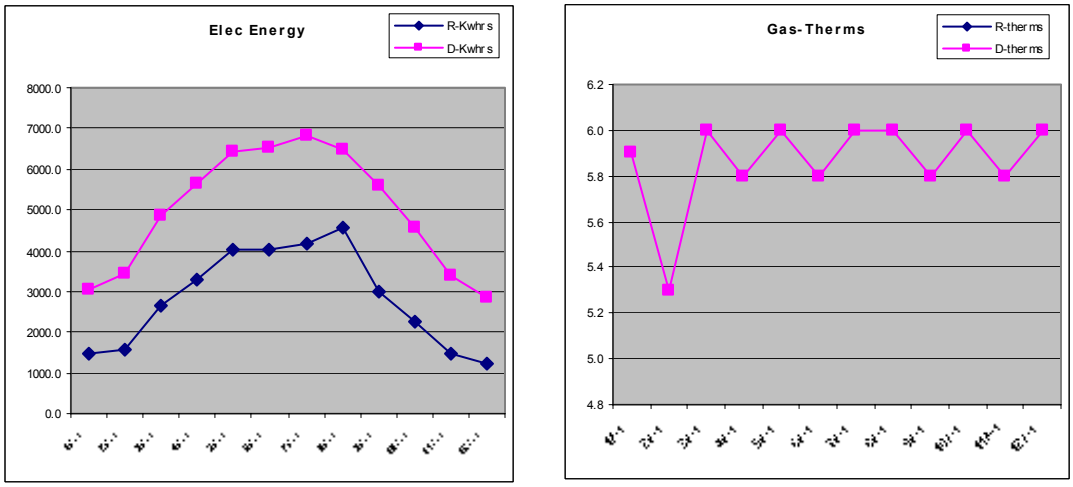


Figure 25: Cooling and heating loads with an east-facing window.

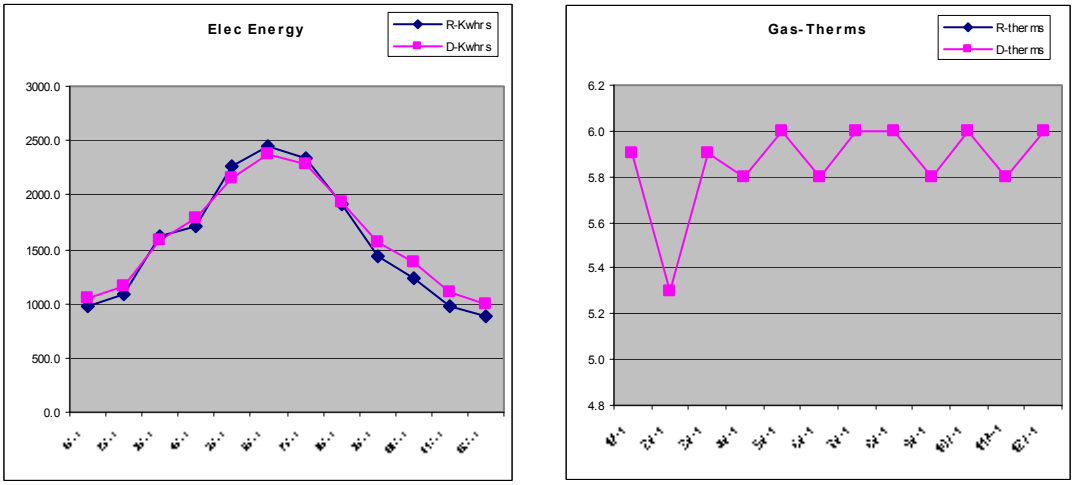


Figure 26: Cooling and heating loads with a north-facing window.

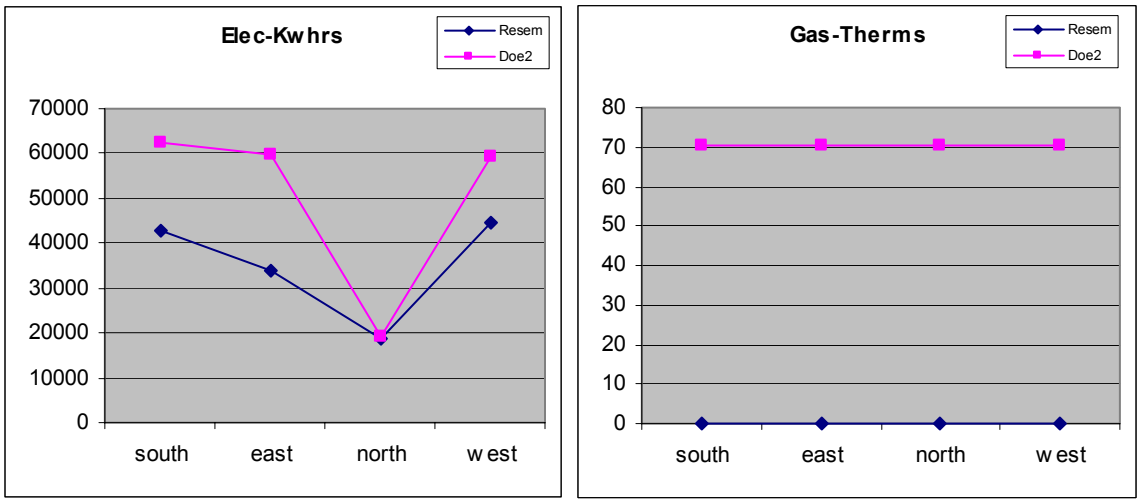


Figure 27: Change in cooling and heating loads with orientation of window, Fresno CA.

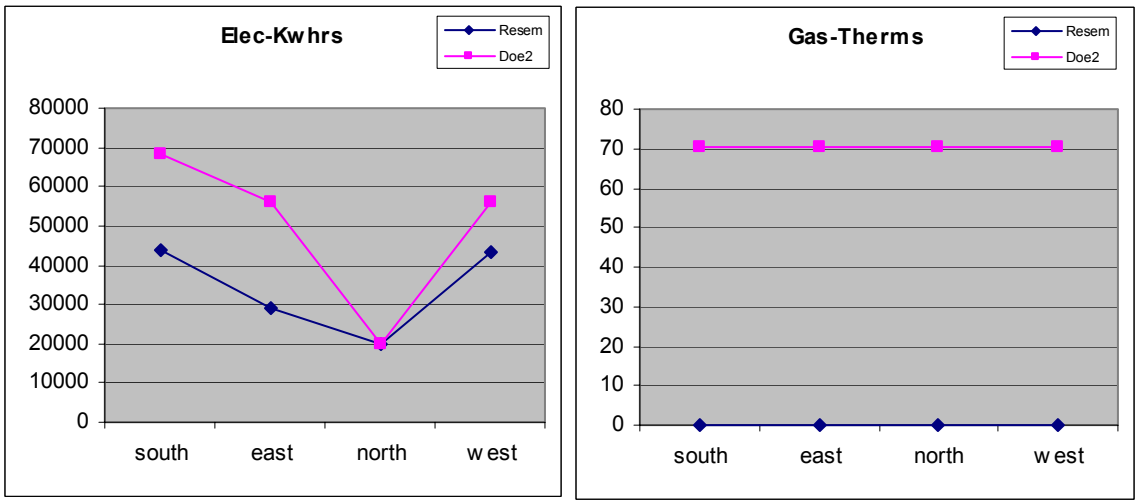


Figure 28: Change in cooling and heating loads with orientation of window, Los Angeles CA.

The results for window orientation confirm the earlier results for wall orientation. RESEM underestimates the solar loads and therefore the cooling loads for the south and east-facing windows. There is good agreement for cooling loads for the north-facing window. In the case of window orientation, unlike the case of wall orientation, the difference between RESEM and DOE2.1E does not change significantly on a monthly basis. There is a slight increase in the differences during the summer months for the south and east-facing windows, but this increase is not as significant as the increase in the case of south and east-facing walls. This suggests that there may be some conduction effects playing a role in the case of walls.

There are essentially no heating loads in the cases considered here. This is because there is solar gain but no conduction or radiation losses. The small amount of heating loads shown for DOE2.1E in Figures 22-26 may be attributable to the boiler pilot.

The results shown in Figure 27 and Figure 28 indicate that both RESEM and DOE2.1E tend to follow the same pattern in how the cooling and heating loads change with orientation of the window. However, DOE2.1E shows larger changes with orientation for cooling loads as compared with RESEM. The differences between RESEM and DOE2.1E are larger for the south and east orientations than for the other orientations. This is true in Fresno as well as Los Angeles. The reasons for these differences need to be explored further. A similar pattern was observed for wall orientation.

3.8. Effect of weather

We considered three different weather locations in California: Fresno (hot, dry climate), Los Angeles (moderate climate), and Arcata (cold climate). The differences between RESEM and DOE2.1E computations do not always show the same pattern across the different climates. This is because several factors play a role in the differences between RESEM and DOE2.1E, and some of these factors are more prominent in one climate rather than the other. For example, direct solar radiation plays a bigger role in a sunny climate and diffuse radiation plays a bigger role in a mostly cloudy climate. Similarly, conduction gains and losses play a bigger role in a more extreme climate rather than a moderate climate.

In this section we look at the effects of weather for the following cases:

- The base case building. (Figure 29, Figure 30, Figure 31).
- *The solar roof*: The base case building with only a roof, but no walls or windows. The solar absorptance of the roof = 0.7, IR emissivity = 0. (Figure 32, Figure 33, Figure 34)
- *The conductive window*: The base case building with only a window in the roof, but no walls or roof. The SC of the window = 0.0, U-value = 1.1. (Figure 35, Figure 36, Figure 37)

The figures below show that both RESEM and DOE2.1E track the differences between the various weather locations, though there are some differences in how they track them.

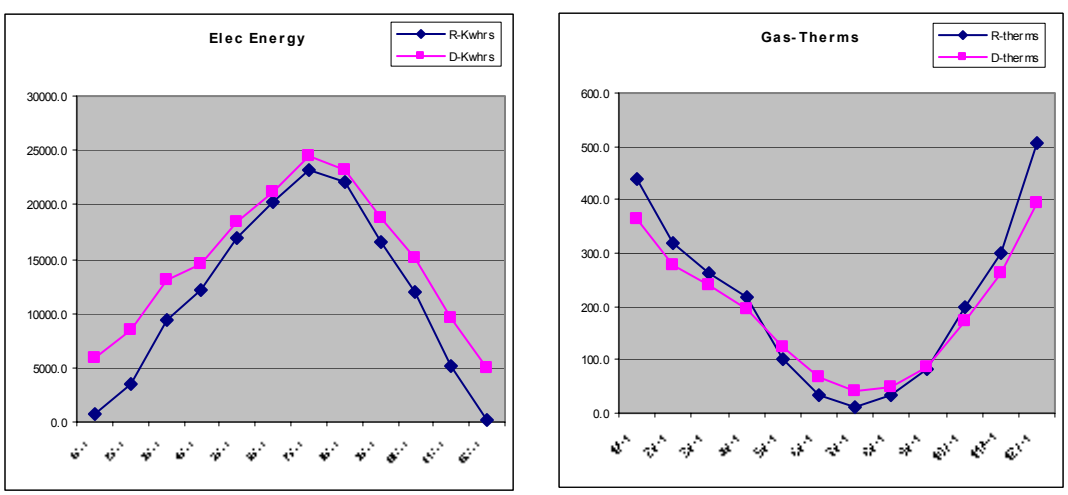


Figure 29: Cooling and heating loads for the base case building, Fresno, CA.

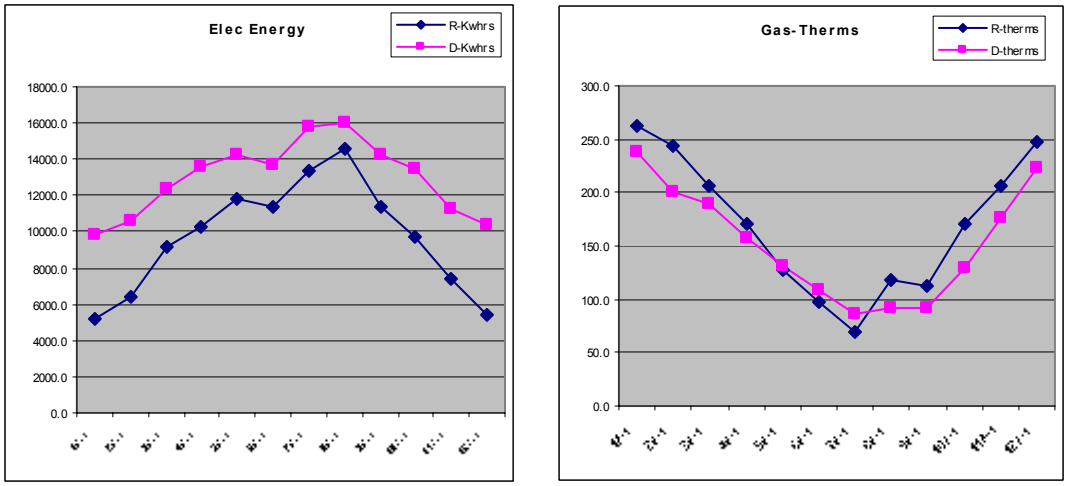


Figure 30: Cooling and heating loads for the base case building, Los Angeles, CA.

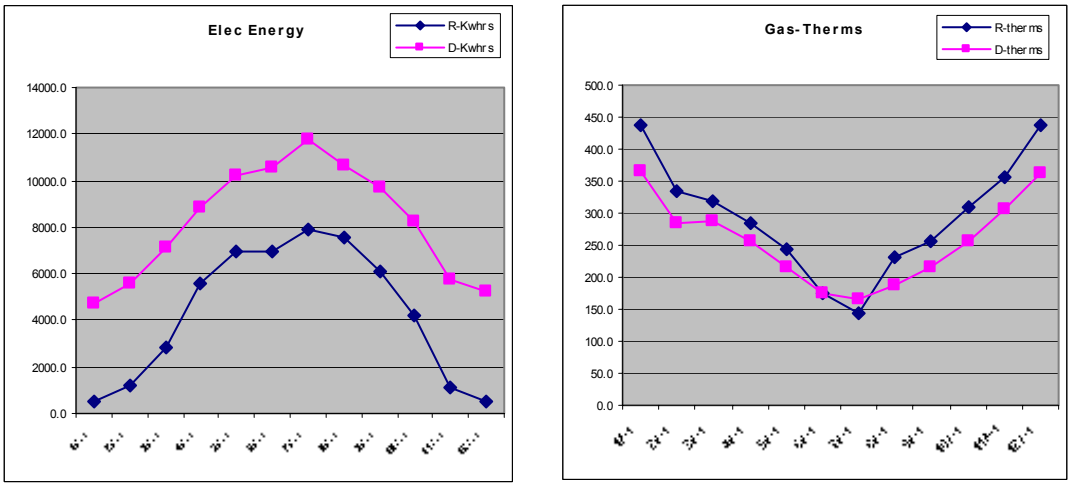


Figure 31: Cooling and heating loads for the base case building, Arcata, CA.

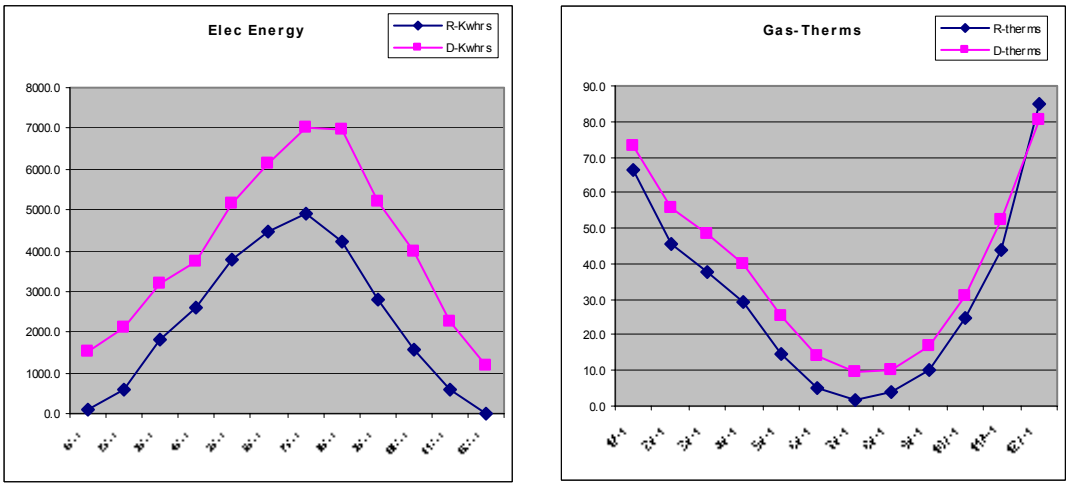


Figure 32: Cooling and heating loads for the base case building with only a roof, Fresno, CA.

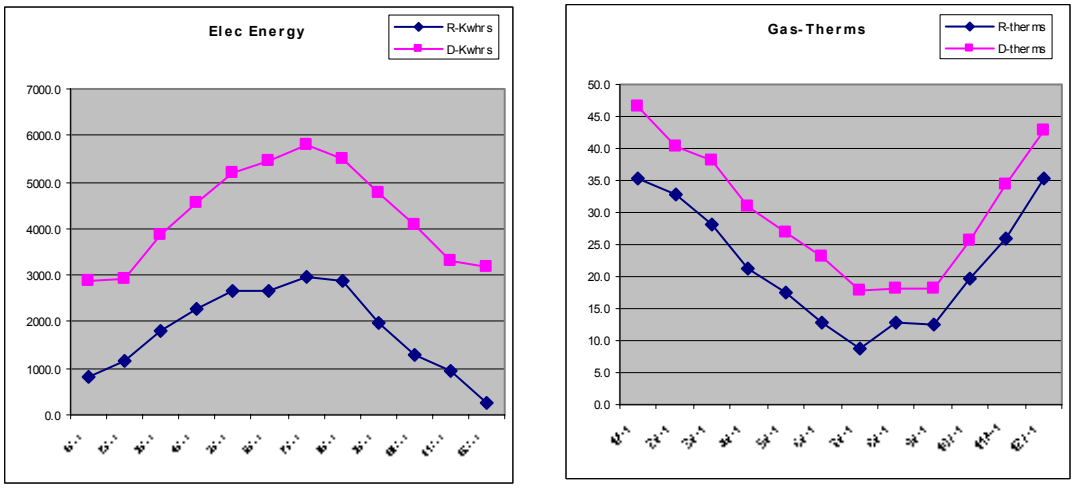


Figure 33: Cooling and heating loads for the base case building with only a roof, Los Angeles, CA.

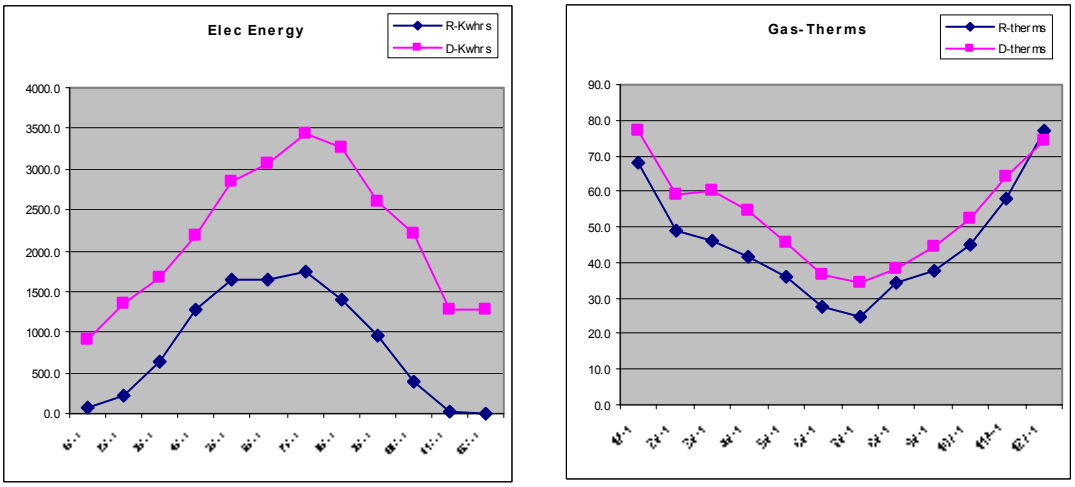


Figure 34: Cooling and heating loads for the base case building with only a roof, Arcata, CA.

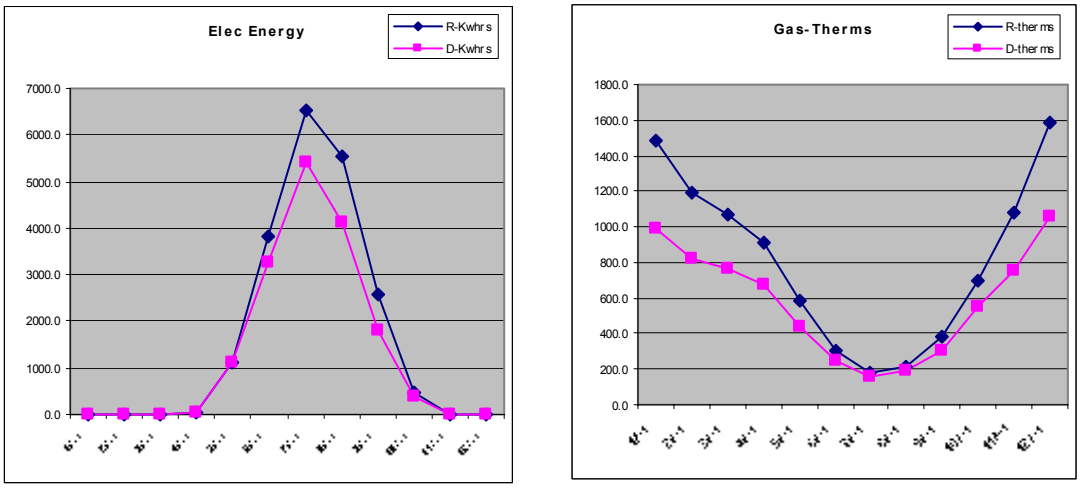


Figure 35: Cooling and heating loads for a roof window with only conductive heat transfer, Fresno.

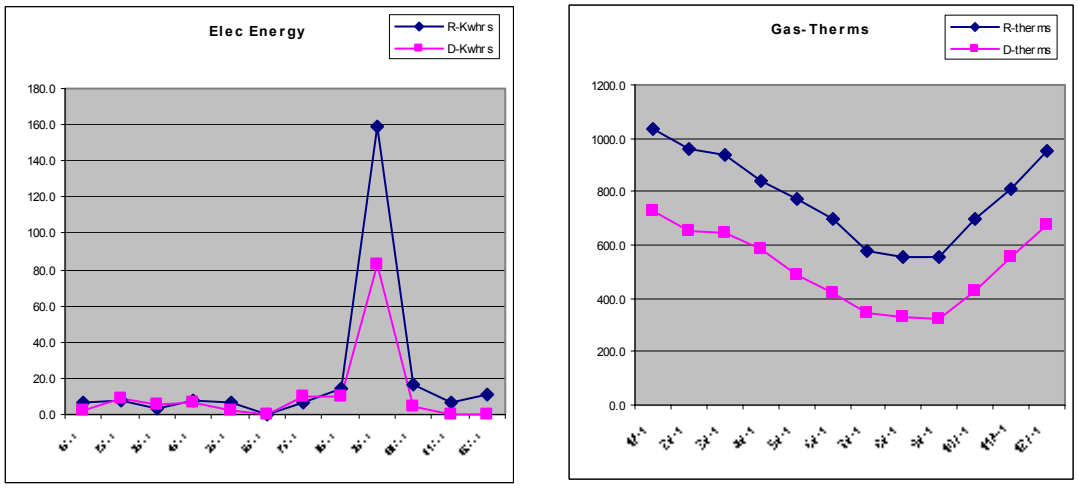


Figure 36: Cooling and heating loads for roof window with only conductive heat loads, Los Angeles.

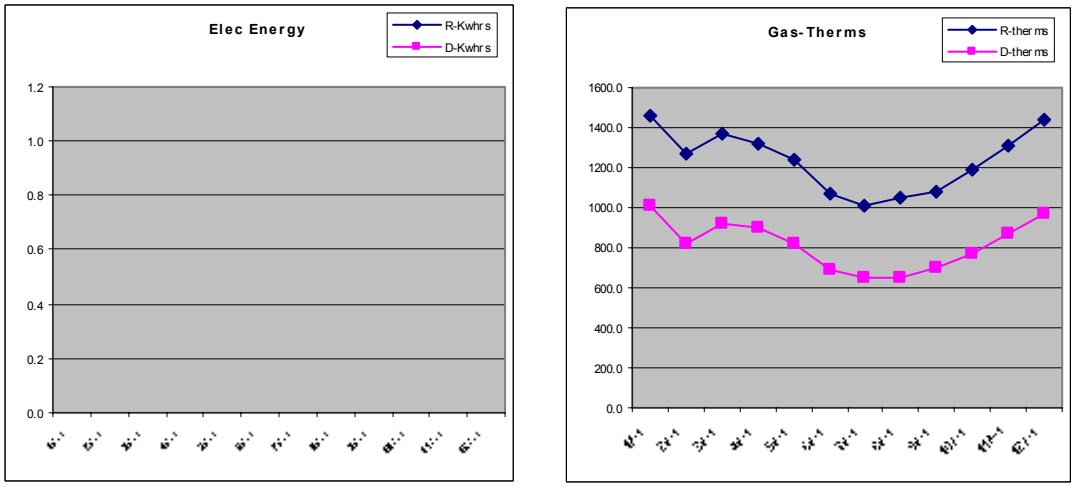


Figure 37: Cooling and heating loads for a roof window with only conductive heat loads, Arcata.

The results show that RESEM follows the same seasonal patterns as demonstrated by DOE2.1E, both for cooling and heating loads, for all three climates. However, RESEM consistently underestimates the cooling loads in all three climates. This underestimation is larger in Los Angeles and Arcata than for Fresno. The differences in cloudiness or temperature patterns between the three climates may be responsible for this. However, looking as Figures 35-37 we can see that the conduction loads (through windows) are not very high, and also do not show as much difference between RESEM and DOE2.1E as solar loads. There are practically no cooling loads due to conduction in Arcata. This indicates that solar radiation has a bigger part to play in differences between RESEM and DOE2.1E with respect to weather location. This is confirmed in Figures 32-34. It is not very clear why the solar load differences between RESEM and DOE2.1E are larger in Los Angeles and Arcata than in Fresno. It could be that Los Angeles and Arcata have more frequent partly cloudy conditions that are modeled differently in RESEM and DOE2.1E.

The differences between the heating load computations by RESEM and DOE2.1E do not vary significantly with weather in the case of the whole base case building (Figures 29-31) or the solar absorbing and conducting roof (Figures 32-34). There are some differences with respect to weather in the case of conduction loads through a roof window (Figures 35-37). In Fresno, there is a monthly variance in the difference between RESEM and DOE2.1E, with smaller differences in summer and larger in winter. In Los Angeles and Arcata, RESEM consistently overestimates heating loads all year round. The reasons for this need to be explored further.

3.9. Relative impact of various load components

Some load components are a larger part of, and thus have greater impacton the magnitude of the electrical and gas energy consumption when these components are non-zero. Thus, small percentage differences between the predictions of the two programs in these cases can have a large absolute impact. This section tries to identify these components. The load components that we considered for this purpose are conduction loads, solar loads, lighting loads and infiltration loads. The following changes were made to the base case building in each case:

- Conduction loads: SC = 0, solar absorptance = 0, IR emissivity = 0.
- Solar loads: U-value of walls, roof and windows = 0, solar absorptance = 0, IR emissivity = 0.
- Lighting loads: U-value of walls, roof and windows = 0, solar absorptance = 0, IR emissivity = 0. In addition, installed lighting power = 1.5 W and lights are on at full power from 7 am to 6 pm daily.
- Infiltration loads: U-value of walls, roof and windows = 0, solar absorptance = 0, IR emissivity = 0. In addition, there is an infiltration rate of 1 ACH during occupied and unoccupied times.

The results are shown in Figure 38. The annual total electrical and gas energy use values are each converted to KBtu to normalize cooling and heating loads.

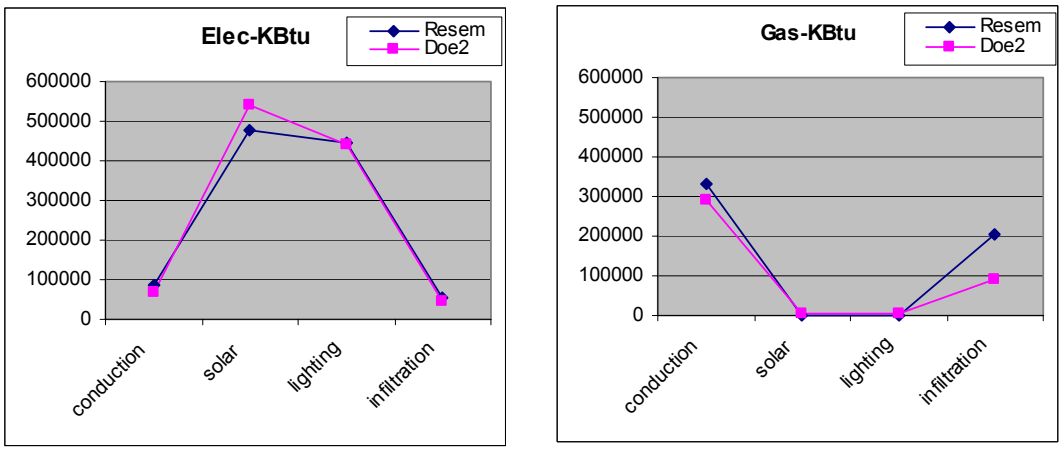


Figure 38: The annual total electrical and gas energy use in Kbtu for various load factors for the Analytical Base Case building.

The results indicate that solar loads and infiltration loads are the biggest components to consider, due to the magnitude of differences in predicted results of RESEM and DOE2.1E for them. The solar loads are a big component in cooling energy use and infiltration in heating energy use. Conduction loads are also a significant component, to a somewhat greater extent in heating energy use than in cooling energy use. As we have seen earlier, most of these differences in conduction loads are due to conduction through windows where the outside air film coefficient plays a big part. Therefore, to minimize the differences between predicted results of RESEM and DOE2.1E, we need to focus our attention on the components identified as important here, i.e. solar loads, infiltration loads and conduction through windows.

4. Validation of predicted change in electrical and gas energy use due to ECM changes

In this part of the analysis, one design parameter of a realistic base case building is varied at a time and the consequent change in annual electrical and gas energy use is computed by RESEM and DOE2.1E and compared. A prototypical five-zone base case building is used for this purpose. The base case building used in this series of tests is called the ECM base-case building since the parametric variations are similar to the Energy Conservation Measures (ECMs) that are used to improve the performance of an existing building. The design parameters include envelope factors (i.e. wall insulation, roof insulation, higher performance glazing, and wall and roof surface treatment such as painting with low absorptance paint), zonal factors (i.e. tightening the envelope to reduce infiltration, installing high efficacy lighting, modifying lighting schedules to utilize daylight or occupancy patterns, and modifying the thermostat settings), plant factors (i.e. heating and cooling plant capacity and efficiency), and system factors (i.e. economizer use, reset temperatures, etc). This part of the analysis is meaningful because RESEM is a retrofit analysis tool and it is important to know how it predicts the effect of various retrofit measures on the energy performance and operating cost of the building.

4.1. ECM Base Case (or Typical) Building

The base case building is a typical 5-zone building of average performance with a VAV system, a central chiller and boiler. It has the following characteristics:

Building geometry, zoning and location:

- 100 ft wide by 100 feet long oriented along the cardinal directions.
- Four perimeter zones on the North, South, East and West with 1250 sq. ft area each. One core zone with 5000 sq. ft area.
- Single floor with height = 10 ft.
- Weather file = Fresno, CA (Hot-dry), Los Angeles (coastal), Arcata (cold).

Envelope:

- Wall U-value = 0.2 [Btu/hr*ft^2*F]
- Roof U-value = 0.09 [Btu/hr*ft^2*F]
- Solar absorptance of walls = 0.7, Solar absorptance of roof = 0.7
- 4 windows, one on each wall, with glazing area = 50% of wall area
- Single glazing, U-value = 1.1 [Btu/hr*ft^2*F], Shading Coefficient = 1.0.

Zone:

- Installed lighting power density = 1.3 [W/sq. ft.]
- Installed equipment power density = 0.75 [W/sq. ft.]
- Density of people = 100 [sq. ft/person], each person's sensible heat load = 255 [btu/hr], each person's latent heat load = 255 [Btu/hr].
- Building operation schedule = "on" from 7 am to 6 pm.
- Infiltration loads = 1 ACH.

Plants and system:

- Heating set-point temperature = 70 F (occupied), 55 F (unoccupied).
- Cooling set-point temperature = 75 F (occupied), 90 F (unoccupied).
- Heating plant = Gas fired hot water boiler with capacity = 0.35 [MBbtu/hr], efficiency = 0.65.
- Cooling plant = Centrifugal chiller with capacity = 1.5 [MBtu/hr], COP = 2.8.
- System = VAV system, one for each zone, with economizer control and no cooling or heating resets.

The complete text of the input files for the ECM Base Case building for RESEM and DOE2.1E is given in Appendix B. Appendix D provides the entire list of the parametric analyses that were performed with the ECM Base Case. All comparisons are for Fresno, CA, unless stated otherwise.

In the following sections, we use the annual total electrical and gas consumption values as the predicted performance metrics to be compared since the ECM cost analysis is based on these values. Future analyses can include comparisons of computed life-cycle costs with available utility rates and schedules.

The Figure 39 gives the comparison between the monthly electrical and gas energy use computed by RESEM and DOE2.1E for the ECM base case building in Fresno. The electrical energy use includes the energy consumption for cooling and direct plug loads. The gas consumption is for heating. Annual electrical energy use computed by RESEM and DOE2.1E is not significantly different, though monthly values show some difference. RESEM overestimates the annual gas consumption by 20% as compared with DOE2.1E. RESEM shows a slightly bigger monthly swing in electrical and gas energy use as compared with DOE2.1E.

Figure 40 and Figure 41 give the corresponding results for Los Angeles and Arcata respectively, and show bigger differences between RESEM and DOE2.1E predictions.

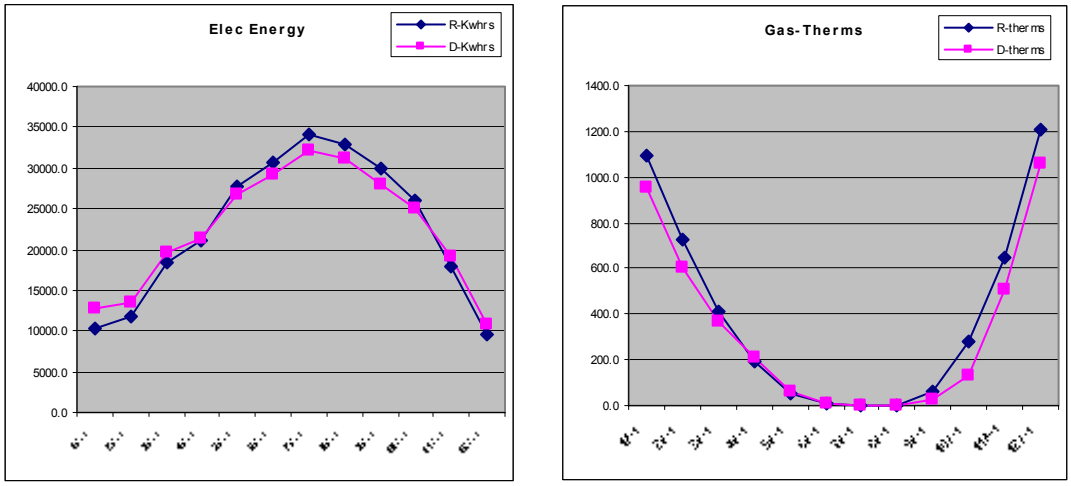


Figure 39: The electrical and gas energy use as computed by RESEM and DOE2.1E in the 5-zone base-case building, Fresno.

Figure 40: The electrical and gas energy use as computed by RESEM and DOE2.1E in the 5-zone base-case building, Los Angeles.

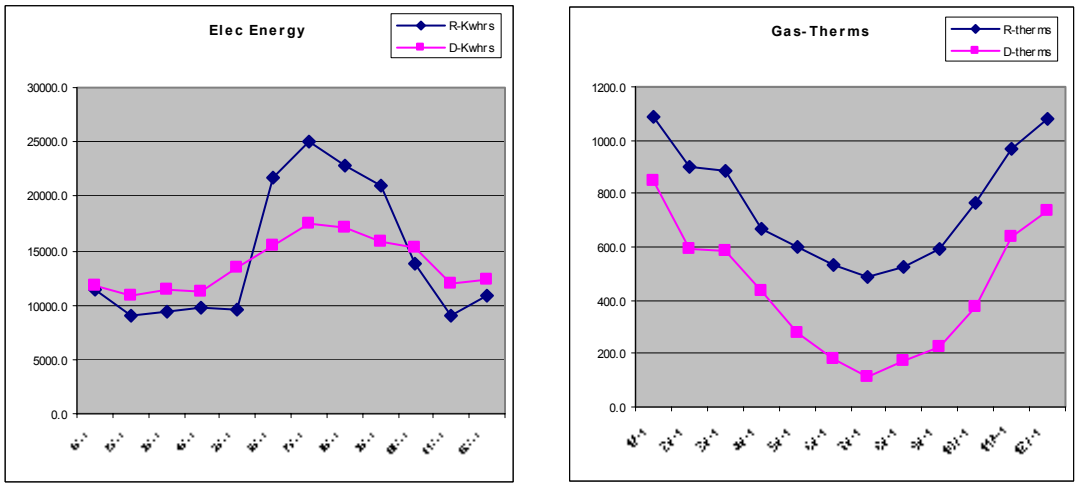


Figure 41: The electrical and gas energy use as computed by RESEM and DOE2.1E in the 5-zone base-case building, Arcata.

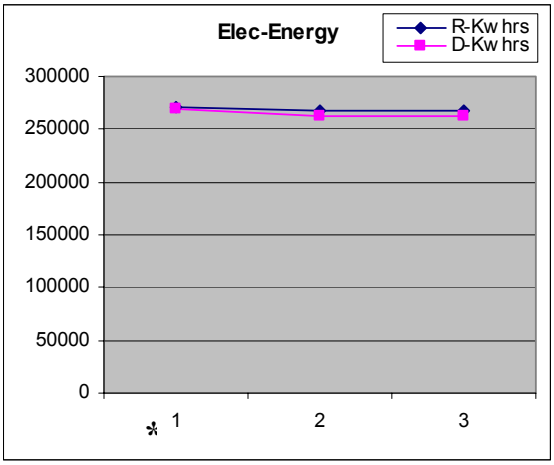
The following sections try to track how these differences change or remain the same with various modifications to the building that represent typical ECMs. These include modifications in the building envelope, in zonal parameters, and in plant and system parameters. This analysis indicates something about the relative sensitivity of the two programs to these parametric variations.

4.2. Building envelope parameters

We looked at the following building envelope parametric variations with the ECM base-case building (The base case is indicated with a star next to it):

- Window U-value and SC (Shading Coefficient)
  (1) * Single clear glazing, U=1.1 [Btu/hr*ft^2*F], SC = 1.0
  (2) Double clear glazing, U=0.57 [Btu/hr*ft^2*F], SC = 0.88
  (3) Double clear glazing with insulating frame, U=0.44 [Btu/hr*ft^2*F], SC = 0.69
- Window area
  (1) * 50% of wall area
  (2) 40% of wall area
  (3) 25% of wall area
- Wall U-value
  (1) * 0.2 [Btu/hr*ft^2*F]
  (2) 0.11 [Btu/hr*ft^2*F]
  (3) 0.06 [Btu/hr*ft^2*F]
- Roof U-value
  (1) * 0.09 [Btu/hr*ft^2*F]
  (2) 0.06 [Btu/hr*ft^2*F]
  (3) 0.03 [Btu/hr*ft^2*F]
- Wall absorptance
  (1) 0.7
  (2) 0.6
  (3) 0.5
- Roof absorptance
  (1) 0.7
  (2) 0.6
  (3) 0.5

Some of these values represent realistic retrofit measures to conserve energy (e.g., wall and roof U-values which can be improved by increased insulation). However, others simply represent a range of values for which RESEM and DOE2.1E computations for annual energy use were compared (e.g. window area, modifying which is not a typical retrofit measure). The Figures below show the annual cooling loads and heating loads as computed by RESEM and DOE2.1E for the above parametric variations, for Fresno.



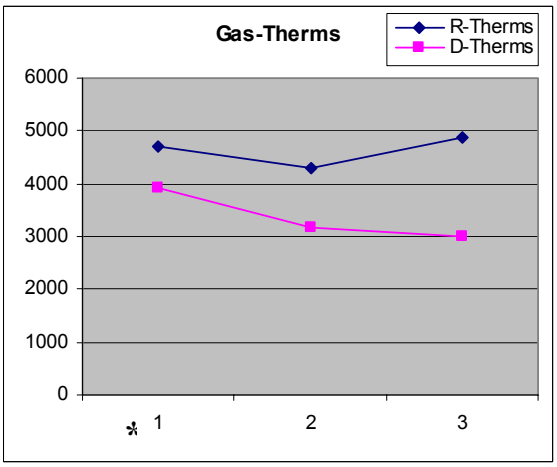


Figure 42: The annual electrical and gas energy use for window U-value and SC parametric variations

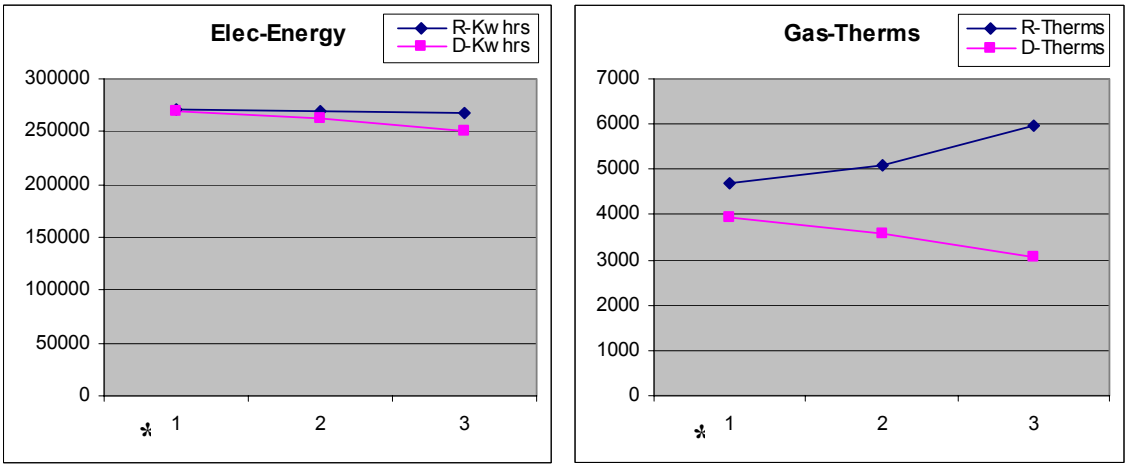


Figure 43: The annual electrical and gas energy use for window area parametric variations

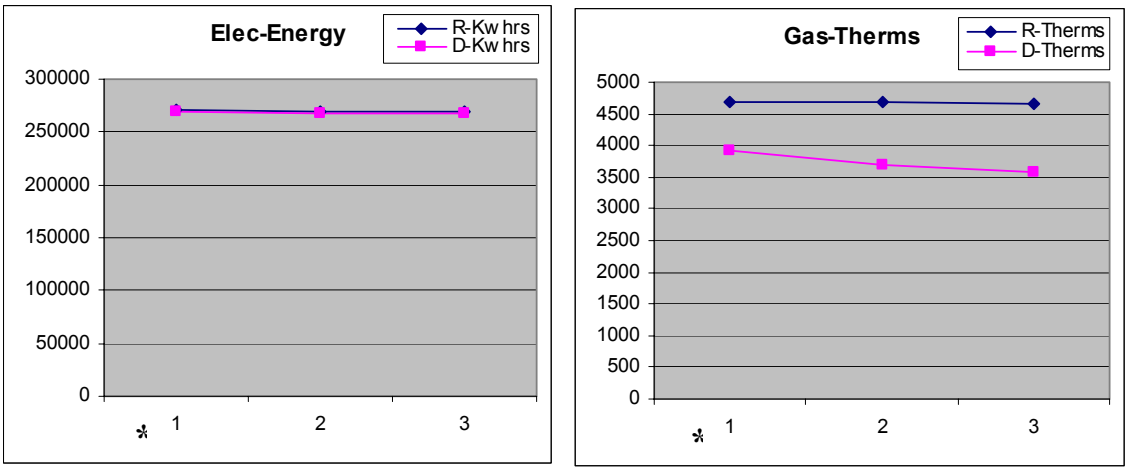


Figure 44: The annual electrical and gas energy use for wall U-value parametric variations

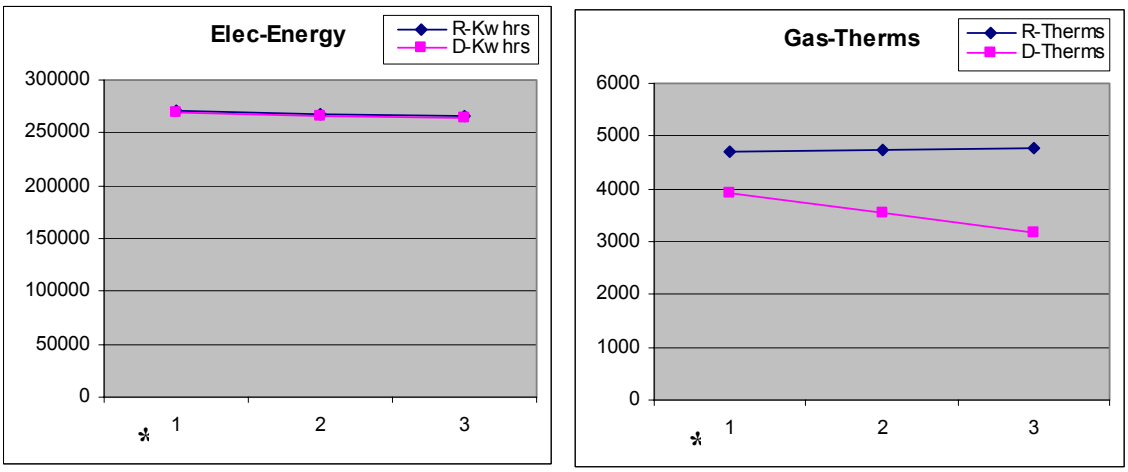


Figure 45: The annual electrical and gas energy use for roof U-value parametric variations

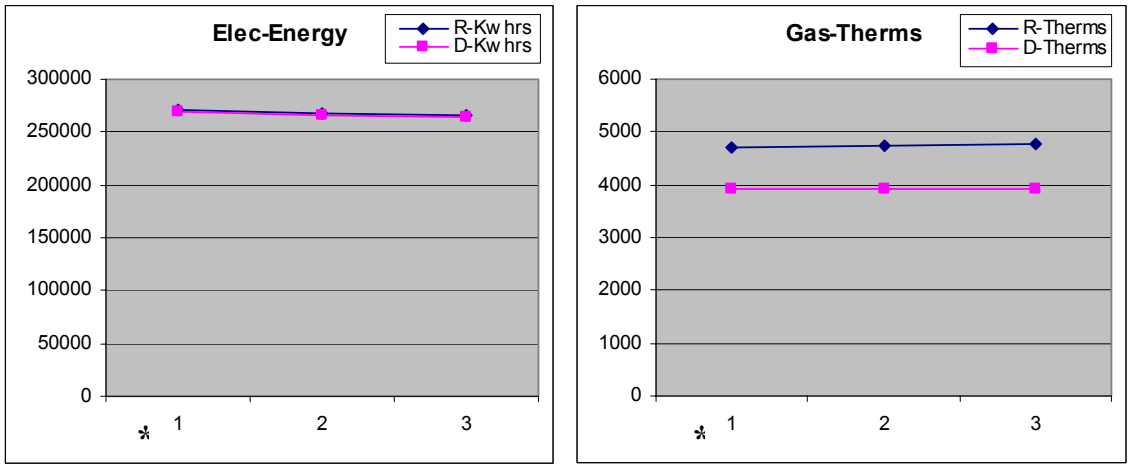


Figure 46: The annual electrical and gas energy use for wall absorptance parametric variations

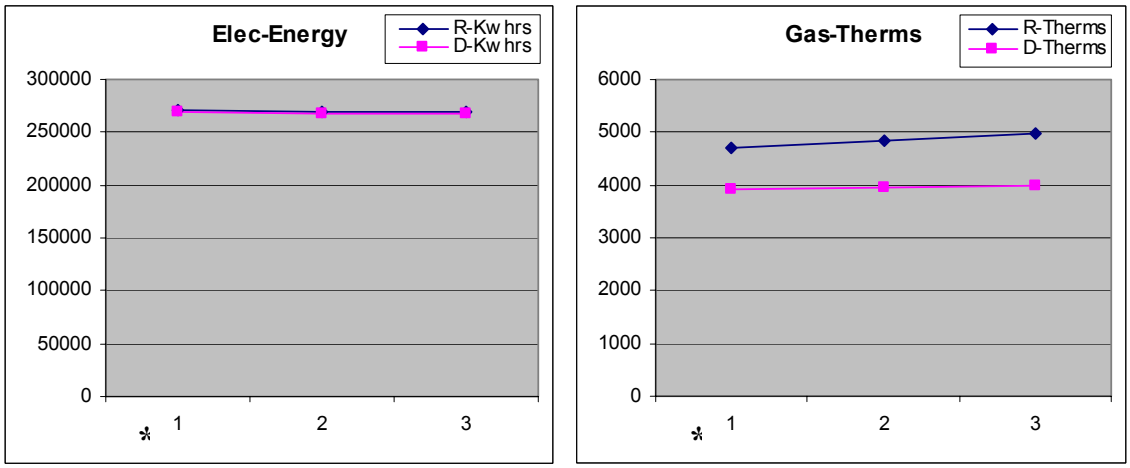


Figure 47: The annual electrical and gas energy use for roof absorptance parametric variations

In general, RESEM shows a different sensitivity to window type and window area as compared with DOE2.1E, especially in the case of gas energy use. We have seen in the previous sections that solar loads are a major source of differences between RESEM and DOE2.1E results. Since solar loads dominate in the case of windows, this may be the reason why there are differences in the sensitivity of RESEM and DOE2.1E to window type and area. RESEM and DOE2.1E show similar sensitivity to wall and roof U-value and absorptance in terms of electrical energy use. However, RESEM shows less sensitivity to U-value and higher sensitivity to absorptance in terms of gas energy use.

With variations in the glazing type (given by U-value and SC), RESEM electrical energy use varies by -1% as compared with -2% for DOE2.1E, and RESEM gas energy use varies by 9 to -4% as compared with 19 to 23% for DOE2.1E. For variations in window area, RESEM electrical energy use varies by -1% as compared with 3 to 7% for

DOE2.1E, and RESEM gas energy use varies by 8 to 27% as compared with -9 to -21% for DOE2.1E. In the remaining cases, the percentage variation in electrical energy use with parametric changes is very similar between RESEM and DOE2.1E, though there are some differences in gas energy use variations. The heating loads in Fresno are low, and big percentage differences can result from small magnitude differences.

4.3. Zone parameters

We looked at the following zonal parametric variations with the ECM base-case building:

- Infiltration rates
  (1) * 1 [ACH]
  (2) 0.75 [ACH]
  (3) 0.5 [ACH]
- Lighting installed power [W/sq. ft]
  (1) 2 [W/sq. ft]
  (2) * 1.5 [W/sq. ft]
  (3) 1 [W/sq. ft]
- Lighting schedules
  (1) * 90% "on" from 8 am to 5 pm, 30% otherwise.
  (2) 90% "on" from 6 am to 6 pm, 30% otherwise.
  (3) 70% "on" from 8 am to 5 pm, 20% otherwise.
- Minimum amount of outside air supplied by the HVAC system
  (1) 10 [cfm/person]
  (2) * 15 [cfm/person]
  (3) 20 [cfm/person]
- Cooling set point temperature
  (1) * 90 F during unoccupied hours, 75 F during occupied hours
  (2) 72 F during unoccupied hours, 72 F during occupied hours
  (3) 85 F during unoccupied hours, 75 F during occupied hours
- Heating set point temperature
  (1) * 55 F during unoccupied hours, 70 F during occupied hours
  (2) 72 F during unoccupied hours, 72 F during occupied hours
  (3) 55 F during unoccupied hours, 68 F during occupied hours

The Figures below show the annual electrical and gas energy use as computed by RESEM and DOE2.1E for the above parametric variations.

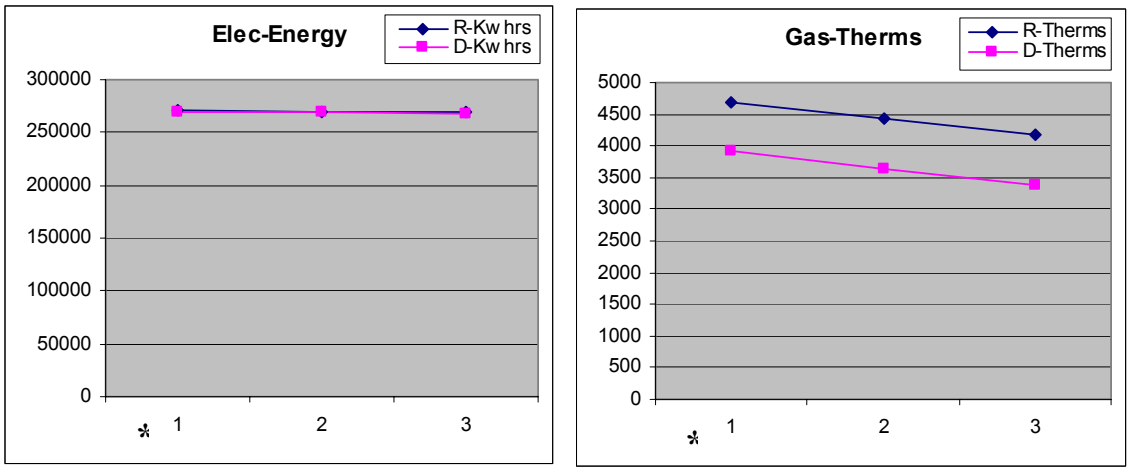


Figure 48: The annual electrical and gas energy use for infiltration rate parametric variations

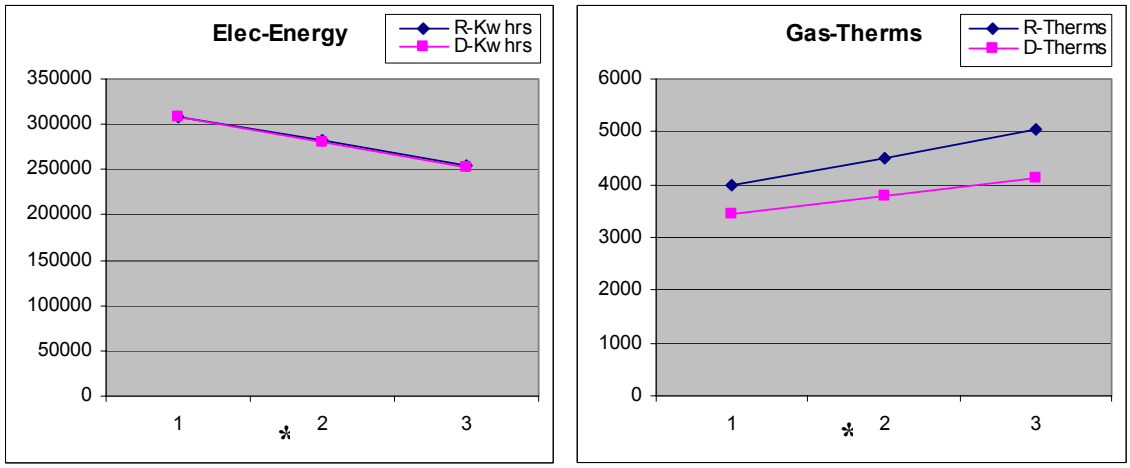


Figure 49: The annual electrical and gas energy use for installed lighting power parametric variations

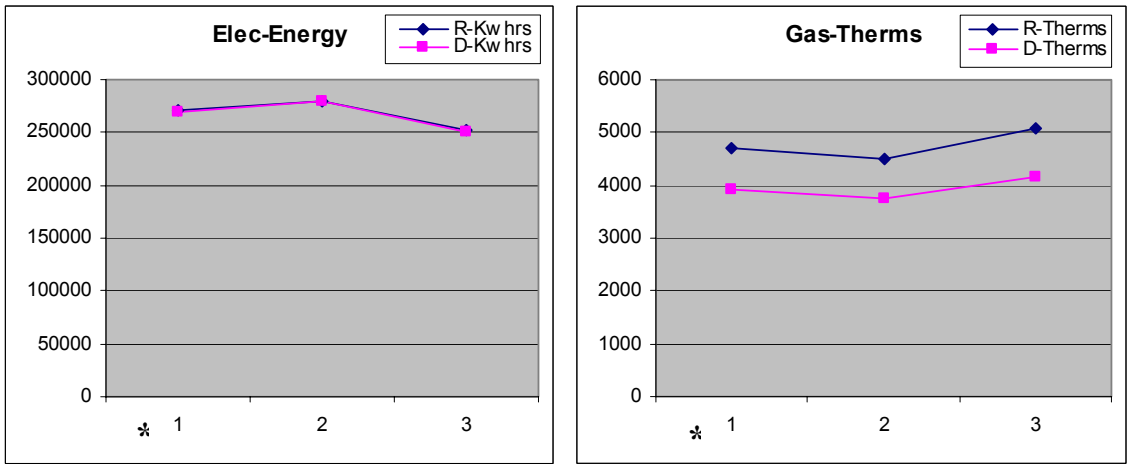


Figure 50: The annual electrical and gas energy use for lighting schedule parametric variations

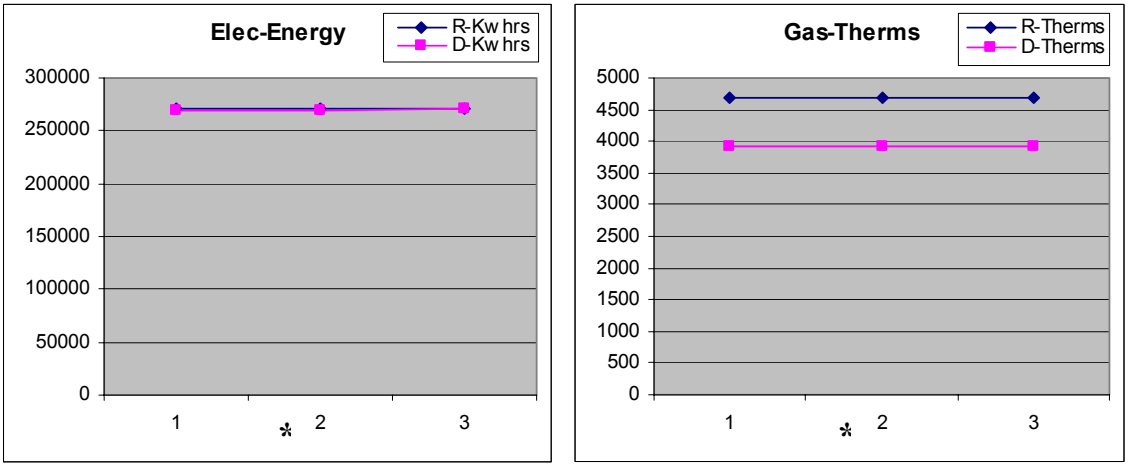


Figure 51: The annual electrical and gas energy use for minimum outside air parametric variations

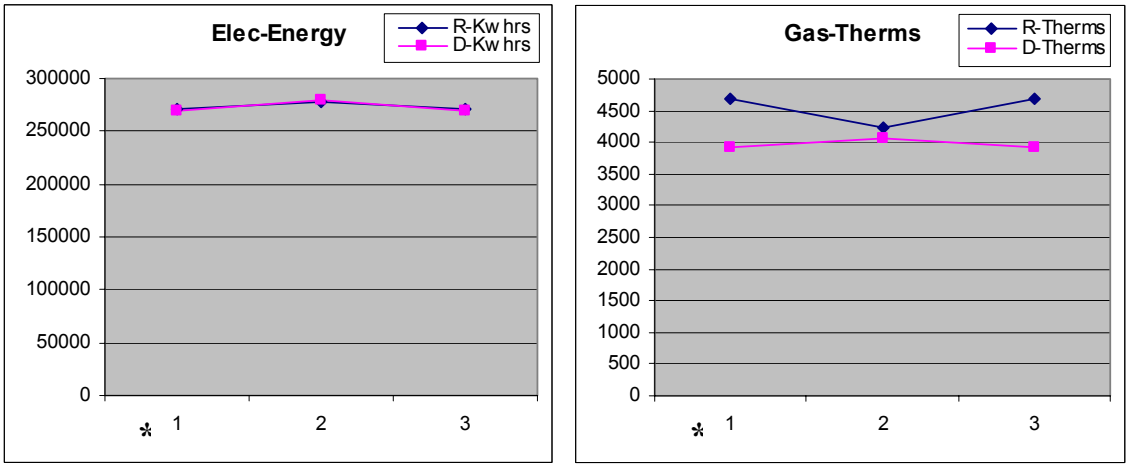


Figure 52: The annual electrical and gas energy use for cooling set point parametric variations

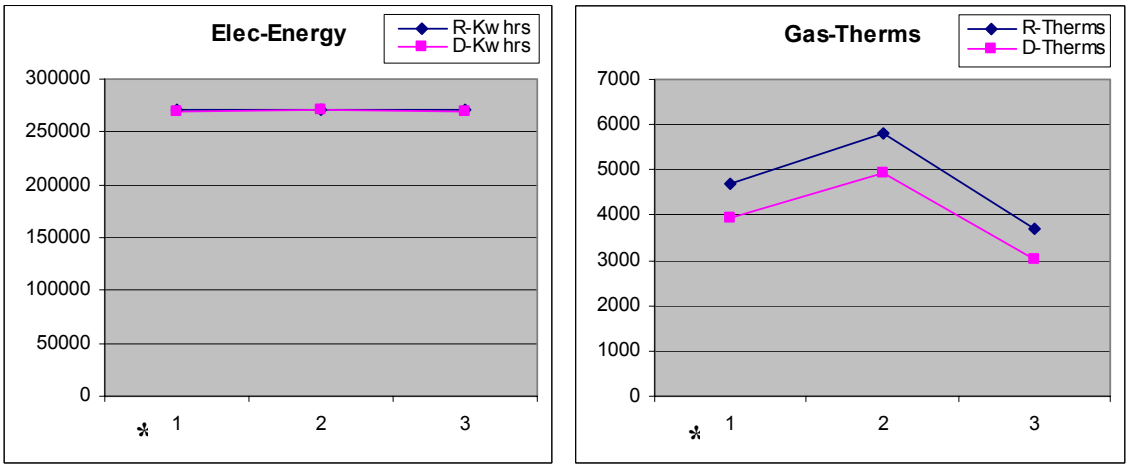


Figure 53: The annual electrical and gas energy use for heating set point parametric variations

The results show that RESEM has a very similar sensitivity to zonal parametric variations as DOE2.1E. This is true for all zonal parametric variations, for both electrical and gas energy use. There is only one exception in the case of gas energy use with variation in cooling set point temperatures. RESEM and DOE2.1E results for gas consumption converge when there is no deadband in the cooling set point temperatures (case 2, Figure 52), but diverge from each other otherwise. The cause(s) for the differences cannot be unambiguously identified with the current comparison data.

With variations in the infiltration rates, RESEM and DOE2.1E electrical energy use varies by 1%, and RESEM gas energy use varies by 6-11% as compared with 7-14% for DOE2.1E. For variations in the lighting power and schedules, RESEM electrical and gas energy use varies almost identically with DOE2.1E. The values for minimum outside air requirements do not have a significant impact on energy use for both RESEM and DOE2.1E. For variations in cooling set point temperatures, RESEM and DOE2.1E have identical variations in electrical energy use (3%), and RESEM gas energy use varies by 10% as compared with 3% for DOE2.1E, and in the opposite direction. The heating set point temperatures do not have a significant effect on electrical energy use, but have a large effect on gas energy use for both RESEM (24 to -21%) and DOE2.1E (26 to -23%).

4.4. Plant parameters

We looked at the following plant parametric variations with the ECM base-case building:

- Heating plant capacity
  (1) 325000 [Btu/hr] (Autosize + 0)
  (2) 406000 [Btu/hr] (Autosize + 25%)
  (3) 488000 [Btu/hr] (Autosize + 50%)
- Heating plant efficiency
  (1) * 0.65
  (2) 0.75
  (3) 0.80
- Cooling plant capacity
  (1) 1320000 [Btu/hr] (Autosize + 0)
  (2) 1650000 [Btu/hr] (Autosize + 25%)
  (3) 1980000 [Btu/hr] (Autosize + 50%)
- Cooling plant design COP
  (1) * 2.8
  (2) 4.0
  (3) 5.0

The figures below show the annual electrical and gas energy use as computed by RESEM and DOE2.1E for the above parametric variations.

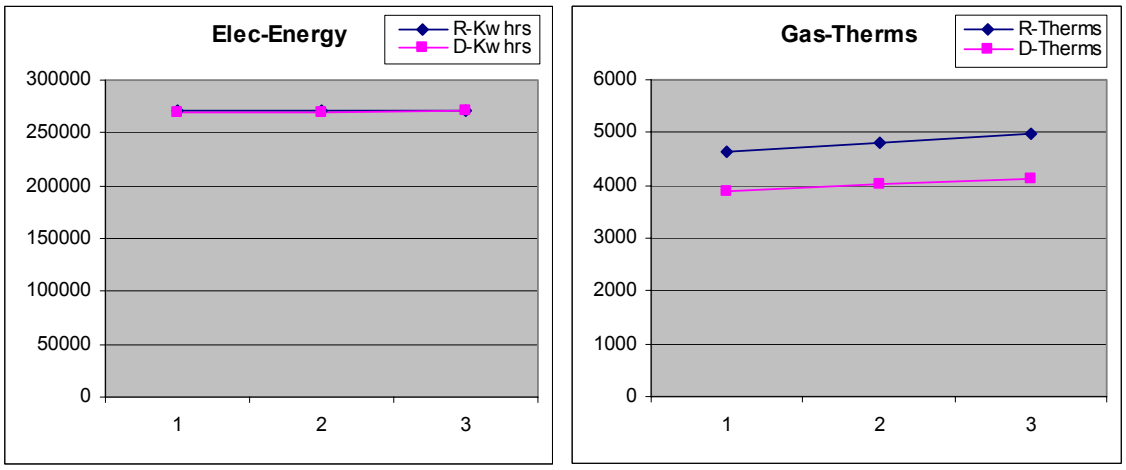


Figure 54: The annual electrical and gas energy use for heating plant capacity parametric variations

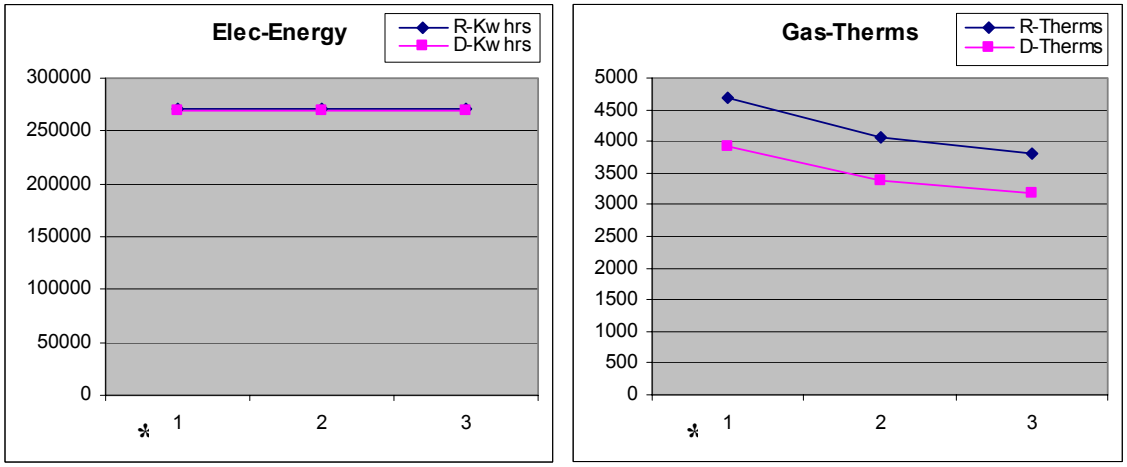


Figure 55: The annual electrical and gas energy use for heating plant efficiency parametric variations

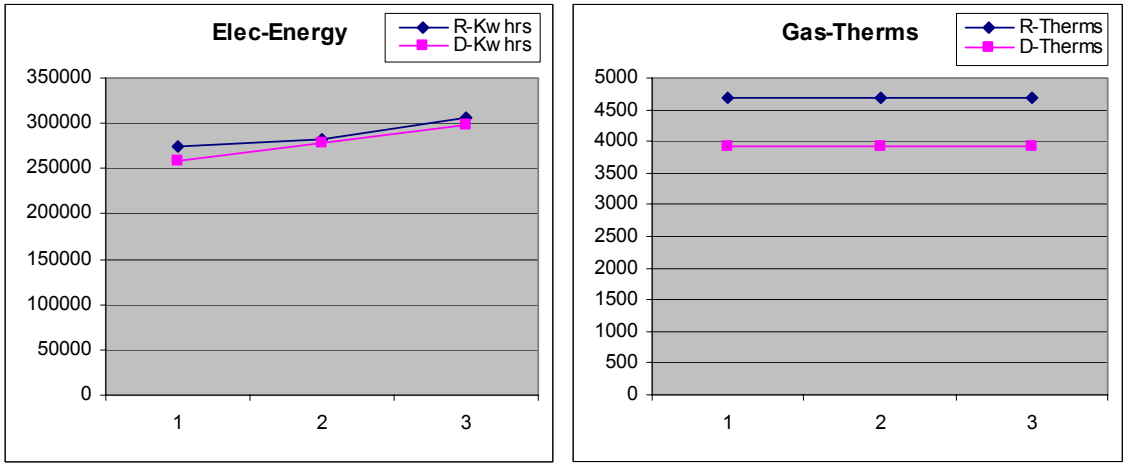


Figure 56: The annual electrical and gas energy use for cooling plant capacity parametric variations

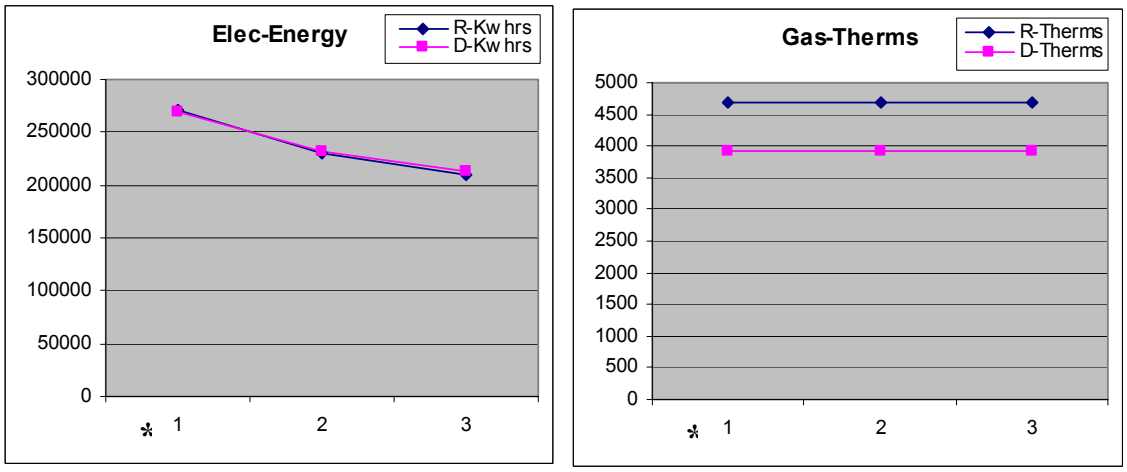


Figure 57: The annual electrical and gas energy use for cooling plant efficiency parametric variations

The sensitivity of annual electrical and gas energy use to parametric variations in plant capacity and efficiency is very similar between RESEM and DOE2.1E. This is true for both the cooling plant and the heating plant.

With variations in the heating plant capacity, RESEM and DOE2.1E electrical energy use does not vary significantly, and RESEM gas energy use varies by 4-7% as compared with 3-6% for DOE2.1E. For variations in the heating plant efficiency, RESEM and DOE2.1E electrical energy use does not vary at all, and RESEM gas energy use varies by 13-19% as compared with 14-19% for DOE2.1E. For variations in the cooling plant capacity and efficiency, the gas energy use does not vary for both RESEM and DOE2.1E. For variations in the cooling plant capacity, RESEM electrical energy use varies by 3-12% as compared with 8-15% for DOE2.1E. For variations in the cooling plant efficiency, RESEM electrical energy use varies by 15-22% as compared with 14-21% for DOE2.1E.

4.5. HVAC system parameters

We looked at the following system parametric variations with the ECM base-case building:

- Economizer
  - (1) No economizer.
  - (2) * Economizer with a limit temperature of 70 F.
- Resets
  - (1) * No reset.
  - (2) Cooling reset, with an outside high limit temperature at which coil reset starts = 70 F, outside low limit temperature at which coil reset stops= 40 F.
- System type
  - (1) * Variable air volume system, with economizer and no reset.
  - (2) Constant volume with reheat system, with economizer and no reset.

The figures below show the annual electrical and gas energy use as computed by RESEM and DOE2.1E for the above parametric variations.

The use of economizer reduces the electrical energy use for both RESEM and DOE2.1E. RESEM is slightly more sensitive to economizer use in terms of electrical energy use, but less sensitive to economizer use in terms of gas energy use that doesn't change significantly with RESEM and increases slightly with DOE2.1E. RESEM is not sensitive to the use of cooling coil resets, but both electrical and gas energy use is reduced with cooling coil resets in DOE2.1E. We need to explore further if different reset temperature schedules would show sensitivity in RESEM. Both RESEM and DOE2.1E show an increase in electrical energy and gas use when we move from a Variable Air Volume system to a Constant Volume with Reheat system.

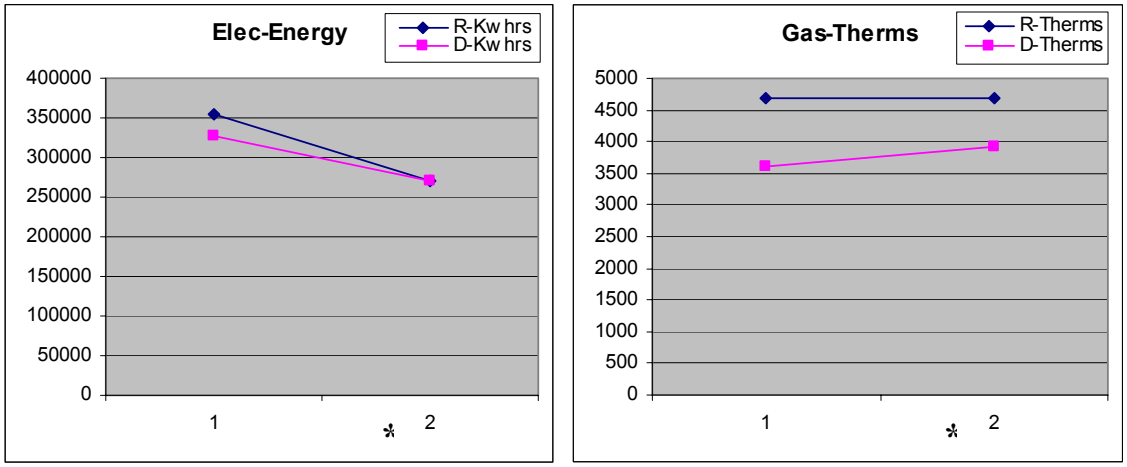


Figure 58: The annual electrical and gas energy use for economizer parametric variations

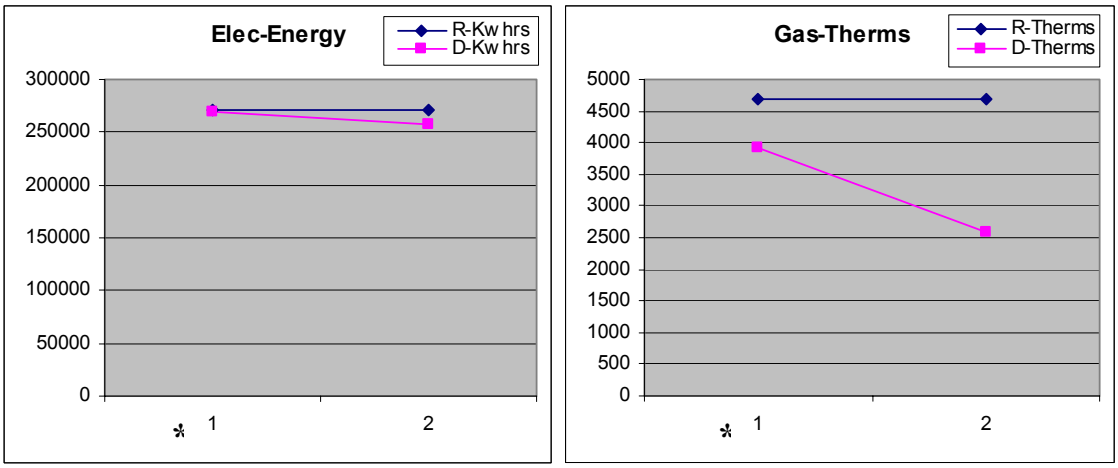


Figure 59: The annual electrical and gas energy use for cooling reset parametric variations

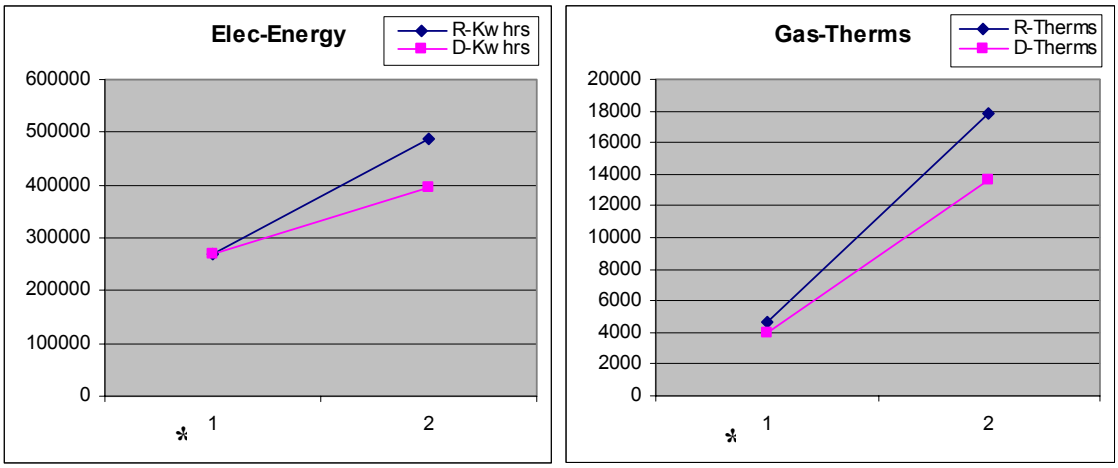


Figure 60: The annual electrical and gas energy use for system type parametric variations

When the economizer is used, RESEM electrical energy use reduces by 18% and DOE2.1E electrical energy use reduces by 24%, and RESEM gas energy use does not change with the use of economizer but DOE2.1E gas use increases by 8%. With the use of cooling coil resets, RESEM electrical and gas energy use does not vary at all, but DOE2.1E electrical energy use reduces by 4% and gas energy use by 34%. For variations in the cooling plant capacity and efficiency, the gas energy use does not vary for both RESEM and DOE2.1E. When the system type is changed from a Variable Volume to a Constant Volume system, RESEM electrical energy use increases by 80% as compared with 46% for DOE2.1E and RESEM gas energy use increases by 279% as compared with 249% for DOE2.1E.

5. Conclusions and recommendations

Though there are some differences in the results of RESEM and DOE2.1E in some cases, there is also very good agreement in other cases. Looking at the components of differences and similarity between RESEM and DOE2.1E, there is a good agreement in computation of conduction loads and internal loads. The lack of agreement in the computation of solar loads and infiltration loads needs to be better understood. Looking at the building as a whole, there is a great deal of similarity in the monthly and annual energy and gas use computed by RESEM and DOE2.1E, with the typical 5-zone building, especially in Fresno (Figure 37). RESEM also shows the same patterns of change as DOE2.1E in most cases, especially with zonal parametric variations.

The following areas show a favorable agreement with DOE2.1E:

1. Prediction of conduction loads.
2. Prediction of internal loads.
3. Monthly patterns of electrical and gas energy use.
4. Sensitivity to variations in building design parameters, especially zonal and plant parameters.

The last two are particularly important in that they indicate that even with differences in some of the load components, RESEM does provide similar "bottom line" results in predictions of the overall effect of ECMs on changing the building energy performance. This is of critical importance for correct retrofit analysis.

The comparison results indicate that the following areas require further exploration and possibly changes to the RESEM algorithms:

1. Computation of solar loads, including the computation of the diffuse and direct components of solar irradiance.
2. Modeling of the outside air film coefficient, and responsiveness of this coefficient to weather conditions.
3. Modeling of Infrared Radiation to the sky, and responsiveness of sky emissivity to weather conditions.
4. Modeling of Infiltration loads.
5. Modeling of reset temperatures and their effect on system energy and gas use.
6. Modeling of building operation periods.

On the whole, this validation study indicates that RESEM is a promising tool for retrofit analysis. As a result of this study some factors (incident solar radiation, outside air film coefficient, IR radiation) have been identified where there is possibility for algorithmic improvements without sacrificing the speed of the tool, which is needed for extensive parametric search of optimum ECM measures.

6. References

1. Hitchcock, R., W.L. Carroll, and B.E. Birdsall, RESEM Reference Manual, Version 1.0, July 1991.

2. DOE-2 Engineer's Manual. Lawrence Berkeley National Laboratory and Los Alamos National Laboratory, Report No. LBL-11353, LA-8520-M, November 1981.

3. Handbook of Fundamantals, American Society of Heating, Cooling and Air-Conditioning Engineers, 1989.

4. G.N. Walton, Thermal Analysis Research Program Reference Manual, U.S Department of Commerce and Department of Energy, March 1983.

5. Perez R., R. Seals, P. Ineichen, R. Stewart, and D. Menicucci, "A New Simplified Version of the Perez Diffuse Irradiance Model for Tilted Surfaces", Solar Energy 39,221-231,1987

Appendix A: The Analytical Base Case Building Input

RESEM

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0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
        on 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
    office 0.00 0.00 0.00 0.00 0.00 0.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00
monsch 2
       off 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
       all 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
occ 0
lgts 0
eqpt 0
misc 0
dhw 0
activity 0
walls 1
   wR10   0.1        E   0.7  0.9
roofs 1
   rR20   0.05       9   0.7     0.9   0
windows 1
   1p-1/8c 1.1 0.9 1.0
bldgsch
  wkdid      office
  satid      office
  sunid      office
htplants 1
 hplant1     sum     gas         all    1  0.0  0.5  1.0   0  2  -1.0  0.0
clplants 1
 cplant1     sum    elec hplant1 all    1  0.0  0.5  1.0   0  1  -1.0  0.0
systems 1
  hvac1      sum cplant1 hplant1 all  all  0.0  0.0    0 0.0  0   0.0  0.0  1  0.0 55.0
0 70.0 70.0 55.0 105.0
nzones 1
zone  1
  zNorth 10000.0  10.0
  nactv  0
  tempH      72.0  72.0
  tempC      72.0  72.0
  inf         0.0   0.0
  mass        0.0
  nwall   4
    wR10  1000.0   0.0  90.0
        nwind 1
           1p-1/8c     500.0   0.0
    wR10  1000.0   90.0  90.0
        nwind 1
           1p-1/8c     500.0   0.0
    wR10  1000.0   180.0  90.0
        nwind 1
           1p-1/8c     500.0   0.0
    wR10  1000.0   270.0  90.0
        nwind 1
           1p-1/8c     500.0   0.0
  nroof   1
    rR20 10000.0  0.0   0.0
               nwind 0
  sysid     hvac1
  zcfm      0.0
  zminOA    0.0
  miscpid   hplant1
  hwpid     hplant1
```

```
mischt 0
miscel 0
```

DOE2.1E

```
POST-PROCESSOR  PARTIAL  ..
INPUT LOADS  ..
TITLE LINE-1 * RESEM reference DOE2 model*
      ..
RUN-PERIOD  JAN 1 1989 THRU DEC 31 1989  ..

BUILDING-LOCATION  LAT 36.80  LON 119.70  ALT 326 T-Z 8
   AZIMUTH 0
   HOLIDAY YES
   DAYLIGHT-SAVINGS YES
   ..
ABORT ERRORS  ..
LIST WARNINGS  ..
PARAMETER  CREDIT-DAYLTG NO  ..

              $ STANDARD OPERATION $
$ OCC $
OCCDAY-1    DAY-SCHEDULE

   $ Occupant schedules
   (1,24) (0.00)  ..

OCC-SCHED SCHEDULE THRU DEC 31
        (WD) OCCDAY-1 (WEH) OCCDAY-1 ..

$ LIT $
LITDAY-1    DAY-SCHEDULE

   $ Lighting schedules
   (1,24) (0.00) ..

LIT-SCHED SCHEDULE THRU DEC 31
        (WD) LITDAY-1 (WEH) LITDAY-1  ..

$ EQP $
EQPDAY-1    DAY-SCHEDULE

   $ Equipment schedules
   (1,24) (0.00) ..

EQP-SCHED SCHEDULE THRU DEC 31
        (WD) EQPDAY-1 (WEH) EQPDAY-1  ..

$ INFILTRATION $
INFIL-1    DAY-SCHEDULE

   $ HVAC schedules
   (1,24) (0.00) ..

INF-SCHED SCHEDULE THRU DEC 31
        (WD) INFIL-1 (WEH) INFIL-1  ..

GT1000 = glass-type  shading-coef = 1.0
                        glass-conductance = 1.47 ..

$ Exterior Surfaces
IN-W MATERIAL  RES = 10000.0 ..
WALL-1 CONSTRUCTION U = 0.1
                    ABSORPTANCE = 0.7 ..

IN-R MATERIAL  RES = 10000.0 ..
ROOF-1 CONSTRUCTION  U = 0.05
                     ABSORPTANCE = 0.7 ..
```

```
FLOOR-1 CONSTRUCTION U = 0.0001 ..


                        $ GENERAL SPACE CHARACTERISTICS $

SPACE-1   SPACE-CONDITIONS
          ZONE-TYPE         = CONDITIONED
          TEMPERATURE       = (72)
          PEOPLE-SCHEDULE   = OCC-SCHED   P-H-S = 255  P-H-L = 255
                                          $ ASHRAE Fund. 26.21
          LIGHTING-SCHEDULE = LIT-SCHED   L-W = 0
          LIGHT-TO-SPACE    = 1.00
          EQUIP-SCHEDULE    = EQP-SCHED   E-W = 0
          INF-SCHEDULE      = INF-SCHED
          INF-METHOD        = AIR-CHANGE
          INF-CFM/SQFT      = 0.001
          FLOOR-WEIGHT      = 0.001
          FURNITURE-TYPE    = LIGHT
          FURN-WEIGHT              = .001
          FURN-FRACTION     = .001
         ..

                         $ SINGLE FLOOR ZONES $

ZSF1     SPACE
         SPACE-CONDITIONS = SPACE-1
         AREA             = 10000
         VOLUME           = 100000
         NUMBER-OF-PEOPLE = 0
         ..

ZFloor   UNDERGROUND-FLOOR
         CONSTRUCTION     = FLOOR-1
         AREA             = 10000
         ..

EWall    EXTERIOR-WALL CONSTRUCTION = WALL-1
         HEIGHT       = 10
         WIDTH        = 100
         AZIMUTH      = 90
         ..

EWndw    WINDOW GLASS-TYPE = GT1000
         HEIGHT =  5
         WIDTH  = 100
          X  = 0
          Y  = 2.5
         ..

SWall    EXTERIOR-WALL CONSTRUCTION = WALL-1
         HEIGHT       = 10
         WIDTH        = 100
         AZIMUTH      = 180
         ..

SWndw    WINDOW GLASS-TYPE = GT1000
         HEIGHT =  5
         WIDTH  = 100
          X  = 0
          Y  = 2.5
         ..

WWall    EXTERIOR-WALL LIKE EWall
         AZIMUTH     = 270 ..

WWndw    WINDOW GLASS-TYPE = GT1000
         HEIGHT =  5
         WIDTH  = 100
          X  = 0
          Y  = 2.5
         ..
```

```
NWall    EXTERIOR-WALL LIKE SWall
         AZIMUTH     = 0 ..

NWndw    WINDOW GLASS-TYPE = GT1000
         HEIGHT =  5
         WIDTH  = 100
          X  = 0
          Y  = 2.5
         ..

ZRoof    ROOF  CONSTRUCTION = ROOF-1
         TILT            = 0.0
         GND-REFLECTANCE = 0.0
         HEIGHT          = 100
         WIDTH           = 100
         ..

                   $ LOADS REPORT DATA $

$ Space peak loads summary, Building peak load components
LOADS-REPORT  V (LV-B,LV-C,LV-I,LV-L)  S (LS-F)  ..

$##endif

END  ..

COMPUTE LOADS  ..

                   $ SYSTEMS DATA $

INPUT SYSTEMS  ..
$ system schedules

FAN-SCHED SCHEDULE THRU DEC 31
    (WD)
   $ HVAC schedules
   (1,6) (0.) (7,18) (1.) (19,24) (0.)

    (WEH)
   $ HVAC schedules
   (1,6) (0.) (7,18) (1.) (19,24) (0.)
  ..

START-Z-FAN SCHEDULE THRU DEC 31
    (WD)
   $ HVAC schedules
   (1,24) (72)

    (WEH)
   $ HVAC schedules
   (1,24) (72)
..

CLG-SCHED SCHEDULE THRU DEC 31
   (WD)
   $ HVAC schedules
   (1,24) (72)

   (WEH)
   $ HVAC schedules
   (1,24) (72)
   ..

HTG-SCHED SCHEDULE THRU DEC 31
   (WD)
   $ HVAC schedules
   (1,24) (72)

   (WEH)
   $ HVAC schedules
```

```
   (1,24) (72)
   ..

ALWAYSOFF SCHEDULE
   THRU DEC 31
   (ALL) (1,24) (0)
   ..

ALWAYSON SCHEDULE
   THRU DEC 31
   (ALL) (1,24) (1)
   ..

$ OCC $
OCCDAY-1    DAY-SCHEDULE

   $ Occupant schedules
   $ no ramping

   (1,24) (0.00)
        ..
OCC-SCHED SCHEDULE THRU DEC 31
        (WD) OCCDAY-1 (WEH) OCCDAY-1
        ..

$ EQP $
EQPDAY-1    DAY-SCHEDULE

   $ Equipment schedules
   $ no ramping

   (1,24) (0.00)
        ..

EQP-SCHED SCHEDULE THRU DEC 31
        (WD) EQPDAY-1 (WEH) EQPDAY-1  ..

$Zone definitions

ZNAIR = ZONE-AIR
        OA-CFM/PER 0. ..

ZNCON = ZONE-CONTROL
        DESIGN-HEAT-T 40
        DESIGN-COOL-T  99
        HEAT-TEMP-SCH HTG-SCHED
        COOL-TEMP-SCH CLG-SCHED
        THERMOSTAT-TYPE PROPORTIONAL
        THROTTLING-RANGE 2
        ..

ZSF1  ZONE
      ZONE-TYPE CONDITIONED
      ZONE-AIR ZNAIR
      ZONE-CONTROL ZNCON
      ..

SYS1     SYSTEM
         SYSTEM-TYPE       SUM
         ZONE-NAMES       (ZSF1)
         SIZING-RATIO      1.0
         HEAT-SOURCE       FURNACE
         FURNACE-HIR       1.0
         MAX-SUPPLY-T      105
         HEAT-SET-T        105
         FAN-SCHEDULE      FAN-SCHED
         NIGHT-CYCLE-CTRL  STAY-OFF
         OA-CONTROL        TEMP
         SUPPLY-EFF        1.0
         SUPPLY-STATIC     3.5
         MIN-SUPPLY-T      55
```

```
          COOLING-EIR       0.284
          INDOOR-FAN-MODE   INTERMITTENT
        ..

                     $ SYSTEM REPORT DATA $

  SYSTEMS-REPORT
       S (SS-A,SS-F,SS-H,SS-J)
  ..

  END  ..
  COMPUTE SYSTEMS ..

                        $ PLANT DATA $
  INPUT PLANT  ..

CLG       P-E TYPE HERM-CENT-CHLR  SIZE -999   I-N 1 ..
          PART-LOAD-RATIO
                   TYPE HERM-CENT-CHLR
                   ELEC-INPUT-RATIO = 1.0 ..
HWG       P-E TYPE HW-BOILER  SIZE -999 I-N 1  ..
               PLANT-PARAMETERS
                       HW-BOILER-HIR = 1.0 ..


  ENERGY-RESOURCE
    RESOURCE NATURAL-GAS ..

                     $ PLANT REPORT DATA $

  PLANT-REPORT
  S (PS-A,PS-B,PS-C,PS-D,PS-G,BEPS,BEPU)  ..
  END  ..
  COMPUTE PLANT  ..
```

Appendix B: The ECM Base Case Building Input

RESEM

```
hrsch 6
       off 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
        on 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
    oc-wkd 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.33 0.67 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.5 0.0
0.0 0.0 0.0 0.0 0.0
    lt-wkd 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.3 0.3
0.3 0.3 0.3 0.3 0.3
    eq-wkd 0.17 0.17 0.17 0.17 0.17 0.17 0.17 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
0.17 0.17 0.17 0.17 0.17 0.17 0.17
    oprn-wkd 0.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0
monsch 5
   sch-off 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
   sch-all 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
    sch-oc 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
    sch-lt 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
    sch-eq 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
occ 1
         people1 100.0 255.0 255.0  oc-wkd
lgts 1
              lgts1     1.3   1.0   0.65        C  lt-wkd
eqpt 1
              eqpt1     0.75        0  eq-wkd
misc 1
              misc0     0.0        0  off
dhw 1
              dhw1      0.0    off
activity 2
   per-wkd
         people1 lgts1    eqpt1             misc0          dhw1
   cor-wkd
         people1 lgts1    eqpt1             misc0          dhw1
walls 1
 WallCons   0.2        E   0.7  0.9
roofs 1
 RoofCons   0.09       12   0.7  0.9   0
windows 1
 WinCons    1.1    0.84  1.0
bldgsch
  wkdid      oprn-wkd
  satid      oprn-wkd
  sunid      oprn-wkd
htplants 1
 hplant1     boiler     gas      sch-all    1  350000.0   0.5  0.65       0   2  -1.0
0.0
clplants 1
 cplant1     centr   elec hplant1  sch-all    1  1500000.0   0.5  2.8       0   1  -1.0
0.0
systems 5
  hvac1      vav  cplant1 hplant1 sch-all  sch-all  3500.0   0.4  1 70.0   0   0.3  0.4
1   0.0 55.0  0 70.0 40.0 55.0 105.0
  hvac2      vav  cplant1 hplant1 sch-all  sch-all  8000.0   0.4  1 70.0   0   0.3  0.4
1   0.0 55.0  0 70.0 40.0 55.0 105.0
  hvac3      vav  cplant1 hplant1 sch-all  sch-all  6200.0   0.4  1 70.0   0   0.3  0.4
1   0.0 55.0  0 70.0 40.0 55.0 105.0
  hvac4      vav  cplant1 hplant1 sch-all  sch-all  7500.0   0.4  1 70.0   0   0.3  0.4
1   0.0 55.0  0 70.0 40.0 55.0 105.0
  hvac5      vav  cplant1 hplant1 sch-all  sch-all  6200.0   0.4  1 70.0   0   0.3  0.4
1   0.0 55.0  0 70.0 40.0 55.0 105.0
nzones 5
```

```
zone  1
  zNorth 1250.0  10.0000
  nactv  1
    per-wkd  1.0  sch-all
  tempH      55.0  70.0
  tempC      90.0  75.0
  inf        1.0   1.0
  mass       2.0
  nwall      1
    WallCons 1000.0   0.0  90.0
        nwind 1
         WinCons 500.0   0.0
  nroof      1
    RoofCons 1250.0  0.0   0.0
      nwind 0
  sysid     hvac1
  zcfm      3500.0
  zminOA    15.0
  miscpid   hplant1
  hwpid     hplant1
zone  2
  zEast 1250.0  10.0000
  nactv  1
    per-wkd  1.0  sch-all
  tempH      55.0  70.0
  tempC      90.0  75.0
  inf        1.0   1.0
  mass       2.0
  nwall      1
    WallCons 1000.0   90.0  90.0
        nwind 1
         WinCons 500.0   0.0
  nroof      1
    RoofCons 1250.0  0.0   0.0
      nwind 0
  sysid     hvac2
  zcfm      8000.0
  zminOA    15.0
  miscpid   hplant1
  hwpid     hplant1
zone  3
  zSouth 1250.0  10.0000
  nactv  1
    per-wkd  1.0  sch-all
  tempH      55.0  70.0
  tempC      90.0  75.0
  inf        1.0   1.0
  mass       2.0
  nwall      1
    WallCons 1000.0   180.0  90.0
        nwind 1
         WinCons 500.0   0.0
  nroof      1
    RoofCons 1250.0  0.0   0.0
      nwind 0
  sysid     hvac3
  zcfm      6200.0
  zminOA    15.0
  miscpid   hplant1
  hwpid     hplant1
zone  4
  zWest 1250.0  10.0000
  nactv  1
    per-wkd  1.0  sch-all
  tempH      55.0  70.0
  tempC      90.0  75.0
  inf        1.0   1.0
  mass       2.0
  nwall      1
    WallCons 1000.0   270.0  90.0
        nwind 1
```

```
        WinCons 500.0   0.0
  nroof      1
    RoofCons 1250.0  0.0   0.0
      nwind 0
  sysid     hvac4
  zcfm      7500.0
  zminOA    15.0
  miscpid   hplant1
  hwpid     hplant1
zone  5
  zCore 5000.0  10.0
  nactv  1
    cor-wkd  1.0  sch-all
  tempH      55.0  70.0
  tempC      90.0  75.0
  inf        1.0   1.0
  mass       2.0
  nwall      0
  nroof      1
    RoofCons 5000.0  0.0   0.0
    nwind 0
  sysid       hvac5
  zcfm     6200.0
  zminOA    15.0000
  miscpid   hplant1
  hwpid     hplant1
mischt 0
miscel 0
```

DOE2.1E

```
  POST-PROCESSOR  PARTIAL  ..
  INPUT LOADS  ..
  TITLE LINE-1 * RESEM reference DOE2 model*
        ..
  RUN-PERIOD  JAN 1 1989 THRU DEC 31 1989  ..

  BUILDING-LOCATION  LAT 36.80  LON 119.70  ALT 326 T-Z 8
     AZIMUTH 0
     HOLIDAY YES
     DAYLIGHT-SAVINGS NO
     ..
  ABORT ERRORS  ..
  LIST WARNINGS  ..
  PARAMETER  CREDIT-DAYLTG NO  ..

               $ STANDARD OPERATION $
  $ OCC $
  OCCDAY-1    DAY-SCHEDULE

     $ Occupant schedules
     (1,7) (0.00)
     (8) ( 0.333333343)
     (9) ( 0.666666627)
     (10,17) (1.00)
     (18) ( 0.500000000)
     (19,24) (0.00) ..


  OCC-SCHED SCHEDULE THRU DEC 31
          (WD) OCCDAY-1 (WEH) OCCDAY-1 ..

  $ LIT $
  LITDAY-1    DAY-SCHEDULE

     $ Lighting schedules
```

```
   (1,7) (0.30)
   (8,17) (0.90)
   (18,24) (0.30) ..

LIT-SCHED SCHEDULE THRU DEC 31
        (WD) LITDAY-1 (WEH) LITDAY-1  ..

$ EQP $
EQPDAY-1    DAY-SCHEDULE

   $ Equipment schedules
   (1,7) (0.17)
   (8,17) (1.00)
   (18,24) (0.17) ..

EQP-SCHED SCHEDULE THRU DEC 31
        (WD) EQPDAY-1 (WEH) EQPDAY-1  ..

$ INFILTRATION $
INFIL-1    DAY-SCHEDULE

   $ HVAC schedules
   (1,6) (1.)
   (7,18) (1.)
   (19,24) (1.) ..

INF-SCHED SCHEDULE THRU DEC 31
        (WD) INFIL-1 (WEH) INFIL-1  ..


$ Window construction
GT-1 = GLASS-TYPE  GLASS-TYPE-CODE = 1000 ..

$ Exterior Surfaces
WALL-1 CONSTRUCTION U = 0.2
                    ABSORPTANCE = 0.7 ..

ROOF-1 CONSTRUCTION  U = 0.09
                     ABSORPTANCE = 0.7 ..

FLOOR-1 CONSTRUCTION U = 0.0001 ..


                        $ GENERAL SPACE CHARACTERISTICS $

SPACE-1   SPACE-CONDITIONS
          ZONE-TYPE         = CONDITIONED
          TEMPERATURE       = (72)
          PEOPLE-SCHEDULE   = OCC-SCHED   P-H-S = 255  P-H-L = 255
          AREA/PERSON       = 100
          LIGHTING-SCHEDULE = LIT-SCHED   L-W = 1.3
          LIGHT-TO-SPACE    = 1.00
          EQUIP-SCHEDULE    = EQP-SCHED   E-W = 0.75
          INF-SCHEDULE      = INF-SCHED
          INF-METHOD        = AIR-CHANGE
          AIR-CHANGES/HR    = 1.0
          FLOOR-WEIGHT      = 70
           SOURCE-SENSIBLE   = 0.0
          ..

                         $ SINGLE FLOOR ZONES $

$ North
NZONE    SPACE
         SPACE-CONDITIONS = SPACE-1
         AREA             = 1250
         VOLUME           = 12500
         ..

NFloor   UNDERGROUND-FLOOR
         CONSTRUCTION     = FLOOR-1
```

```
          AREA             = 1250
          ..

  NWall   EXTERIOR-WALL CONSTRUCTION = WALL-1
          HEIGHT       = 10
          WIDTH        = 100
          AZIMUTH     = 0
          outside-emiss = 0.9
          ..

  NWndw   WINDOW GLASS-TYPE = GT-1
          HEIGHT =  5
          WIDTH  = 100
           X  = 0
           Y  = 2.5
          ..

  NRoof   ROOF  CONSTRUCTION = ROOF-1
          TILT            = 0.0
          GND-REFLECTANCE = 0.0
          HEIGHT          = 12.5
          WIDTH           = 100
          outside-emiss = 0.9
          ..

  $ South
  SZONE   SPACE
          SPACE-CONDITIONS = SPACE-1
          AREA             = 1250
          VOLUME           = 12500
          ..

  SFloor  UNDERGROUND-FLOOR
          CONSTRUCTION     = FLOOR-1
          AREA             = 1250
          ..

  SWall   EXTERIOR-WALL CONSTRUCTION = WALL-1
          HEIGHT       = 10
          WIDTH        = 100
          AZIMUTH     = 180
          outside-emiss = 0.9
          ..

  SWndw   WINDOW GLASS-TYPE = GT-1
          HEIGHT =  5
          WIDTH  = 100
           X  = 0
           Y  = 2.5
          ..

  SRoof   ROOF  CONSTRUCTION = ROOF-1
          TILT            = 0.0
          GND-REFLECTANCE = 0.0
          HEIGHT          = 12.5
          WIDTH           = 100
          outside-emiss = 0.9
          ..

$ East
  EZONE   SPACE
          SPACE-CONDITIONS = SPACE-1
          AREA             = 1250
          VOLUME           = 12500
          ..

  EFloor  UNDERGROUND-FLOOR
          CONSTRUCTION     = FLOOR-1
          AREA             = 1250
          ..
```

```
  EWall    EXTERIOR-WALL CONSTRUCTION = WALL-1
           HEIGHT       = 10
           WIDTH        = 100
           AZIMUTH     = 90
           outside-emiss = 0.9
           ..

  EWndw    WINDOW GLASS-TYPE = GT-1
           HEIGHT =  5
           WIDTH  = 100
            X  = 0
            Y  = 2.5
           ..

  ERoof    ROOF  CONSTRUCTION = ROOF-1
           TILT            = 0.0
           GND-REFLECTANCE = 0.0
           HEIGHT          = 12.5
           WIDTH           = 100
           outside-emiss = 0.9
           ..

$ West
  WZONE    SPACE
           SPACE-CONDITIONS = SPACE-1
           AREA             = 1250
           VOLUME           = 12500
           ..

  WFloor   UNDERGROUND-FLOOR
           CONSTRUCTION     = FLOOR-1
           AREA             = 1250
           ..

  WWall    EXTERIOR-WALL CONSTRUCTION = WALL-1
           HEIGHT       = 10
           WIDTH        = 100
           AZIMUTH     = 270
           outside-emiss = 0.9
           ..

  WWndw    WINDOW GLASS-TYPE = GT-1
           HEIGHT =  5
           WIDTH  = 100
            X  = 0
            Y  = 2.5
           ..

  WRoof    ROOF  CONSTRUCTION = ROOF-1
           TILT            = 0.0
           GND-REFLECTANCE = 0.0
           HEIGHT          = 12.5
           WIDTH           = 100
           outside-emiss = 0.9
           ..

$ Core
  CORE     SPACE
           SPACE-CONDITIONS = SPACE-1
           AREA             = 5000
           VOLUME           = 50000
           ..

  CFloor   UNDERGROUND-FLOOR
           CONSTRUCTION     = FLOOR-1
           AREA             = 5000
           ..

  CRoof    ROOF  CONSTRUCTION = ROOF-1
           TILT            = 0.0
           GND-REFLECTANCE = 0.0
```

```
         HEIGHT          = 70.71
         WIDTH           = 70.71
         outside-emiss = 0.9
         ..


                    $ LOADS REPORT DATA $

$ Space peak loads summary, Building peak load components
LOADS-REPORT  V (LV-B,LV-C,LV-I,LV-L)  S (LS-F)  ..

$##endif

END  ..

COMPUTE LOADS  ..

                   $ SYSTEMS DATA $

INPUT SYSTEMS  ..
$ system schedules

FAN-SCHED SCHEDULE THRU DEC 31
    (WD)
   $ HVAC schedules
   $(1,24) (1.)
   (1,6) (0.) (7,18) (1.) (19,24) (0.)

    (WEH)
   $ HVAC schedules
   $(1,24) (1.)
   (1,6) (0.) (7,18) (1.) (19,24) (0.)
  ..

CLG-SCHED SCHEDULE THRU DEC 31
   (WD)
   $ HVAC schedules
   (1,6) (90)
   (7,18) (75)
   (19,24) (90)


   (WEH)
   $ HVAC schedules
   (1,6) (90)
   (7,18) (75)
   (19,24) (90)
   ..

HTG-SCHED SCHEDULE THRU DEC 31
   (WD)
   $ HVAC schedules
   (1,6) (55)
   (7,18) (70)
   (19,24) (55)

   (WEH)
   $ HVAC schedules
   (1,6) (55)
   (7,18) (70)
   (19,24) (55)
   ..

ALWAYSOFF SCHEDULE
   THRU DEC 31
   (ALL) (1,24) (0)
   ..

ALWAYSON SCHEDULE
   THRU DEC 31
```

```
   (ALL) (1,24) (1)
   ..

$Zone definitions

NZONE   ZONE
  ZONE-TYPE = CONDITIONED
  DESIGN-HEAT-T = 70
  DESIGN-COOL-T = 75
  HEAT-TEMP-SCH = HTG-SCHED
  COOL-TEMP-SCH = CLG-SCHED
  OA-CFM/PER = 15.0
  $CFM/SQFT = 1.0
  ..

SZONE  ZONE  LIKE  NZONE   ..
EZONE  ZONE  LIKE  NZONE   ..
WZONE  ZONE  LIKE  NZONE   ..
CORE   ZONE  LIKE  NZONE   ..


SYS1 = SYSTEM
  S-TYPE = VAVS
  $ SYSTEM-TYPE = SUM
  ZONE-NAMES = (NZONE)
  COOL-SET-T       55
  HEAT-SET-T           105
  MIN-SUPPLY-T     55
  MAX-SUPPLY-T     105
  OA-CONTROL       TEMP
  E-L-T = 70.00
  HEAT-SIZING-RATIO = 1.0
  COOL-SIZING-RATIO = 1.0
  FAN-SCHEDULE  =   FAN-SCHED
  FAN-CONTROL = SPEED
  REHEAT-DELTA-T   50
  HEAT-SOURCE      HOT-WATER
  SUPPLY-KW = 0.0004
  MIN-CFM-RATIO = 0.4
  MIN-OUTSIDE-AIR = 0.3
  ..

 SYS2 = SYSTEM
  S-TYPE = VAVS
  $ SYSTEM-TYPE = SUM
  ZONE-NAMES = (SZONE)
  COOL-SET-T       55
  HEAT-SET-T           105
  MIN-SUPPLY-T     55
  MAX-SUPPLY-T     105
  OA-CONTROL       TEMP
  E-L-T = 70.00
  HEAT-SIZING-RATIO = 1.0
  COOL-SIZING-RATIO = 1.0
  FAN-SCHEDULE  =   FAN-SCHED
  FAN-CONTROL = SPEED
  REHEAT-DELTA-T   50
  HEAT-SOURCE      HOT-WATER
  SUPPLY-KW = 0.0004
  MIN-CFM-RATIO = 0.4
  MIN-OUTSIDE-AIR = 0.3
  ..

SYS3 = SYSTEM
  S-TYPE = VAVS
  $ SYSTEM-TYPE = SUM
  ZONE-NAMES = (EZONE)
  COOL-SET-T       55
  HEAT-SET-T           105
  MIN-SUPPLY-T     55
  MAX-SUPPLY-T     105
```

```
  OA-CONTROL       TEMP
  E-L-T = 70.00
  HEAT-SIZING-RATIO = 1.0
  COOL-SIZING-RATIO = 1.0
  FAN-SCHEDULE  =   FAN-SCHED
  FAN-CONTROL = SPEED
  REHEAT-DELTA-T   50
  HEAT-SOURCE      HOT-WATER
  SUPPLY-KW = 0.0004
  MIN-CFM-RATIO = 0.4
  MIN-OUTSIDE-AIR = 0.3
  ..

SYS4 = SYSTEM
  S-TYPE = VAVS
  $ SYSTEM-TYPE = SUM
  ZONE-NAMES = (WZONE)
  COOL-SET-T       55
  HEAT-SET-T           105
  MIN-SUPPLY-T     55
  MAX-SUPPLY-T     105
  OA-CONTROL       TEMP
  E-L-T = 70.00
  HEAT-SIZING-RATIO = 1.0
  COOL-SIZING-RATIO = 1.0
  FAN-SCHEDULE  =   FAN-SCHED
  FAN-CONTROL = SPEED
  REHEAT-DELTA-T   50
  HEAT-SOURCE      HOT-WATER
  SUPPLY-KW = 0.0004
  MIN-CFM-RATIO = 0.4
  MIN-OUTSIDE-AIR = 0.3
  ..

SYS5 = SYSTEM
  S-TYPE = VAVS
  $ SYSTEM-TYPE = SUM
  ZONE-NAMES = (CORE)
  COOL-SET-T       55
  HEAT-SET-T           105
  MIN-SUPPLY-T     55
  MAX-SUPPLY-T     105
  OA-CONTROL       TEMP
  E-L-T = 70.00
  HEAT-SIZING-RATIO = 1.0
  COOL-SIZING-RATIO = 1.0
  FAN-SCHEDULE  =   FAN-SCHED
  FAN-CONTROL = SPEED
  REHEAT-DELTA-T   50
  HEAT-SOURCE      HOT-WATER
  SUPPLY-KW = 0.0004
  MIN-CFM-RATIO = 0.4
  MIN-OUTSIDE-AIR = 0.3
  ..


                    $ SYSTEM REPORT DATA $

SYSTEMS-REPORT
     S (SS-A,SS-F,SS-H,SS-J)
..

END  ..
COMPUTE SYSTEMS ..

                       $ PLANT DATA $
INPUT PLANT  ..

CLG       P-E TYPE HERM-CENT-CHLR  SIZE 1.5 INSTALLED-NUMBER 1 ..
          PART-LOAD-RATIO
                 TYPE HERM-CENT-CHLR
```

```
                $ ELEC-INPUT-RATIO = 1.0 ..
                ELEC-INPUT-RATIO = 0.36 ..
HWG       P-E TYPE HW-BOILER  SIZE 0.35 INSTALLED-NUMBER 1 ..
            PLANT-PARAMETERS
                    $ HW-BOILER-HIR = 1.0 ..
                    HW-BOILER-HIR = 1.54 ..

                  $ PLANT REPORT DATA $

PLANT-REPORT
S (PS-A,PS-B,PS-C,PS-D,PS-G,BEPS,BEPU)  ..
END  ..
COMPUTE PLANT  ..
```

Appendix C: The Analytical Base Case Runs

*(Filenames are in **bold**)*

ABC_1a: Whole building, walls, windows, everything (IR, SC, sol-abs, U-value) is on.
ABC_1b: Whole building, walls, windows, SC = 0.
ABC_1c: Whole building, walls, windows, Solar absorptance = 0.
ABC_1d: Whole building, walls, windows, thermostat settings = H (58, 68), C (86, 74).
ABC_1e: Whole building, walls, windows, infiltration ACH = 1.0.
ABC_1f: Whole building, walls, windows, Lighting loads > 0.
ABC_1g: Whole building, walls, windows, everything (IR, SC, sol-abs, U-value) is on, CVCT system, centrifugal chiller, hot water boiler.
ABC_2a: Roof only, solar abs = 0.7, IR = 0.9.
ABC_2b: Roof only, solar abs = 0.7, IR = 0.
ABC_2c: Roof only, solar abs = 0, IR = 0.9.
ABC_2d: Roof only, solar abs = 0, IR = 0.
ABC_3a: South wall only, solar abs = 0.7, IR = 0.9.
ABC_3b: South wall only, solar abs = 0.7, IR = 0.
ABC_3c: South wall only, solar abs = 0, IR = 0.9.
ABC_3d: South wall only, solar abs = 0, IR = 0.
ABC_3e: East wall only, solar abs = 0.7, IR = 0.9.
ABC_3f: East wall only, solar abs = 0.7, IR = 0.
ABC_3g: East wall only, solar abs = 0, IR = 0.9.
ABC_3h: East wall only, solar abs = 0, IR = 0.
ABC_3i: North wall only, solar abs = 0.7, IR = 0.9.
ABC_3j: North wall only, solar abs = 0.7, IR = 0.
ABC_3k: North wall only, solar abs = 0, IR = 0.9.
ABC_3l: North wall only, solar abs = 0, IR = 0.
ABC_3m: West wall only, solar abs = 0.7, IR = 0.9.
ABC_3n: West wall only, solar abs = 0.7, IR = 0.
ABC_3o: West wall only, solar abs = 0, IR = 0.9.
ABC_3p: West wall only, solar abs = 0, IR = 0.
ABC_4a: All walls, roof, no windows, solar abs = 0.7, IR = 0.9.
ABC_4b: All walls, roof, no windows, solar abs = 0.7, IR = 0.
ABC_4c: All walls, roof, no windows, solar abs = 0, IR = 0.9.
ABC_4d: All walls, roof, no windows, solar abs = 0, IR = 0.
ABC_5a: No walls, no roof, South window, SC = 1, U = 1.1
ABC_5b: No walls, no roof, South window, SC = 0, U = 1.1
ABC_5c: No walls, no roof, South window, SC = 1, U = 0
ABC_5d: No walls, no roof, East window, SC = 1, U = 1.1
ABC_5e: No walls, no roof, East window, SC = 0, U = 1.1
ABC_5f: No walls, no roof, East window, SC = 1, U = 0
ABC_5g: No walls, no roof, North window, SC = 1, U = 1.1
ABC_5h: No walls, no roof, North window, SC = 0, U = 1.1
ABC_5i: No walls, no roof, North window, SC = 1, U = 0

ABC_5j: No walls, no roof, West window, SC = 1, U = 1.1
ABC_5k: No walls, no roof, West window, SC = 0, U = 1.1
ABC_5l: No walls, no roof, West window, SC = 1, U = 0
ABC_5m: No walls, no roof, Roof window, SC = 1, U = 1.1
ABC_5n: No walls, no roof, Roof window, SC = 0, U = 1.1
ABC_5o: No walls, no roof, Roof window, SC = 1, U = 0
ABC_6a: Whole building, south window only, everything (IR, SC, abs, U-value) is on.
ABC_6b: Whole building, east window only, everything (IR, SC, abs, U-value) is on.
ABC_6c: Whole building, north window only, everything (IR, SC, abs, U-value) is on.
ABC_6d: Whole building, west window only, everything (IR, SC, abs, U-value) is on.

Appendix D: The ECM Base Case Runs

*(Filenames are in **bold**)*

Window U-value and SC (Shading Coefficient):

ECM_wind_a5: Single clear glazing, U=1.1 [Btu/hr*ft^2*F], SC = 1.0
ECM_wind_b5: Double clear glazing, U=0.57 [Btu/hr*ft^2*F], SC = 0.88
ECM_wind_c5: Double clear glazing with insulating frame, U=0.44 [Btu/hr*ft^2*F], SC = 0.69

Window area:

ECM_windarea_a5: 50% of wall area
ECM_windarea_b5: 40% of wall area
ECM_windarea_c5: 25% of wall area

Wall U-value:

ECM_wallU_a5: 0.2 [Btu/hr*ft^2*F]
ECM_wallU_b5: 0.11 [Btu/hr*ft^2*F]
ECM_wallU_c5: 0.06 [Btu/hr*ft^2*F]

Roof U-value:

ECM_roofU_a5: 0.09 [Btu/hr*ft^2*F]
ECM_roofU_b5: 0.06 [Btu/hr*ft^2*F]
ECM_roofU_c5: 0.03 [Btu/hr*ft^2*F]

Wall absorptance:

ECM_wallAbs_a5: 0.7
ECM_wallAbs_b5: 0.6
ECM_wallAbs_c5: 0.5

Roof absorptance:

ECM_roofAbs_a5: 0.7
ECM_roofAbs_b5: 0.6
ECM_roofAbs_c5: 0.5

Infiltration rates:

ECM_inf_a5: 1 [ACH]
ECM_inf_b5: 0.75 [ACH]
ECM_inf_c5: 0.5 [ACH]

Lighting installed power:

ECM_lgts_a5: 2 [W/sq. ft]
ECM_lgts_b5: 1.5 [W/sq. ft]
ECM_lgts_c5: 1 [W/sq. ft]

Lighting schedules:

ECM_lgtsch_a5: 90% "on" from 8 am to 5 pm, 30% otherwise.
ECM_lgtsch_b5: 90% "on" from 6 am to 6 pm, 30% otherwise.
ECM_lgtsch_c5: 70% "on" from 8 am to 5 pm, 20% otherwise.

Minimum amount of outside air supplied by the HVAC system:

ECM_minOA_a5: 10 [cfm/person]
ECM_minOA_b5: 15 [cfm/person]
ECM_minOA_c5: 20 [cfm/person]

Cooling set point temperature:

ECM_coolset_a5: 90 F during unoccupied hours, 75 F during occupied hours
ECM_coolset_b5: 72 F during unoccupied hours, 72 F during occupied hours
ECM_coolset_c5: 85 F during unoccupied hours, 75 F during occupied hours

Heating set point temperature:

ECM_heatset_a5: 55 F during unoccupied hours, 70 F during occupied hours
ECM_heatset_b5: 72 F during unoccupied hours, 72 F during occupied hours
ECM_heatset_c5: 55 F during unoccupied hours, 68 F during occupied hours

Heating plant capacity:

ECM_HplantCAP_a5: 325000 [Btu/hr] (Autosize + 0)
ECM_HplantCAP_b5: 406000 [Btu/hr] (Autosize + 25%)
ECM_HplantCAP_c5: 488000 [Btu/hr] (Autosize + 50%)

Heating plant efficiency:

ECM_HplantEff_a5: 0.65
ECM_HplantEff_b5: 0.75
ECM_HplantEff_c5: 0.80

Cooling plant capacity:

ECM_CplantCAP_a5: 1320000 [Btu/hr] (Autosize + 0)
ECM_CplantCAP_b5: 1650000 [Btu/hr] (Autosize + 25%)
ECM_CplantCAP_c5: 1980000 [Btu/hr] (Autosize + 50%)

Cooling plant design COP:

ECM_CplantEff_a5: 2.8
ECM_CplantEff_b5: 4.0
ECM_CplantEff_c5: 5.0

Economizer:

ECM_Econo_a5: No economizer.
ECM_Econo_b5: Economizer with a limit temperature of 70 F.

Resets:

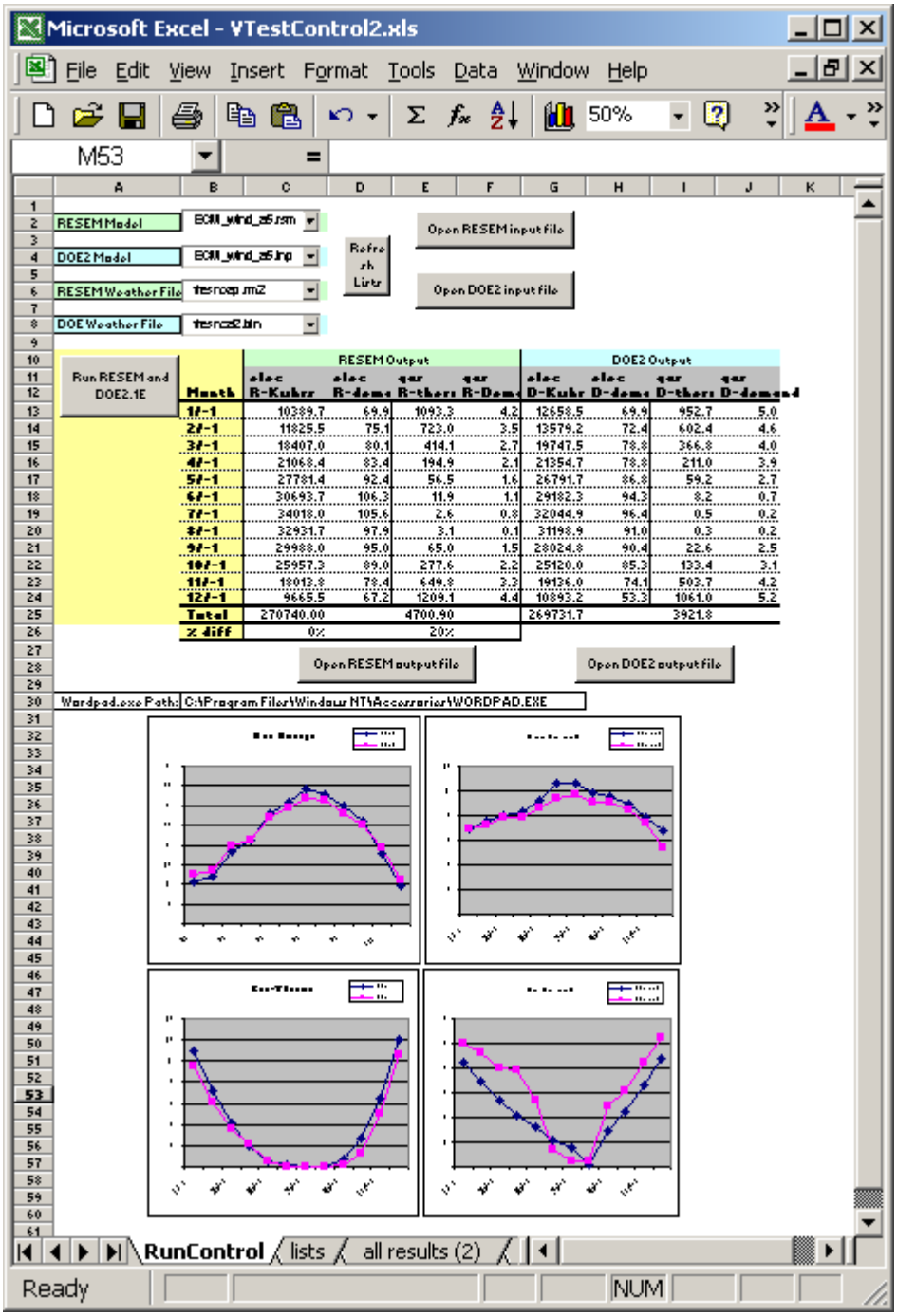
ECM_reset_a5: No reset.
ECM_reset_b5: Cooling reset, with an outside high limit temperature at which coil reset starts = 70 F, outside low limit temperature at which coil reset stops= 40 F.

System type:

ECM_system_a5: Variable air volume system.
ECM_system_b5: Constant volume with reheat system.

Appendix E: Tool for RESEM validation

(Developed by Norman Bourassa, LBNL)



A major issue with comparing RESEM-CA and DOE2.1E results is the large difference between output formats. To facilitate the comparison of RESEM-CA and DOE2.1E

results, an Excel spreadsheet that quickly executes simulations and extracts the compatible results has been developed. The tool allows the user to select from a drop menu the RESEM and DOE-2 input files and weather locations to run. The models are run simultaneously, with results updated into formatted tables and graphs. This drastically helps reduce the amount time involved in the iterative process of calibrating the RESEM-CA model.

This tool runs the simulations for RESEM and DOE2.1E with the selected input files and weather locations, and then populates the table and graphs with selected results from the output files generated. The input files and weather files can be loaded in the pull-down menus by clicking on "Refresh Lists". We can view and/or edit input and output files by clicking on the respective "Open" buttons. The code is written in Visual Basic for Applications (VBA).