HOT-2000 PROGRAM
COMPARISON/VALIDATION WITH
U.S. BLAST 3.0 COMPUTER PROGRAM

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DISCLAIMER

NOTE

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With U.S. Blast 3.0 Computer Program

TABLE OF CONTENTS

Index of Figures

HOT2000 PROGRAM COMPARISON/VALIDATION
WITH U.S. BLAST 3.0 COMPUTER PROGRAM

Summary

This work was undertaken to compare the BLAST 3.0 program with results of a previous study, "HOT2000 Program Comparison/Validation with U.S. DOE2.1D Computer Program", and with a more recent version HOT2000 (6.03i).

Building models constructed for the previous study, including simple "box" structures, and a relatively realistic model for a small house, were prepared for the BLAST program. A set of 15 weather files were assembled using the BLAST weather processor. Sets of runs were done for each model to investigate the effect of climate, or the variation of selected building parameters on heating and cooling loads.

The results of this study indicate that for series Res10, the differences between BLAST and HOT2000 annual heating loads are generally less than those obtained for DOE 2.1D. Annual cooling loads obtained by HOT2000 average about 10% less than the corresponding loads calculated by DOE2 and BLAST.

The monthly heating and cooling loads obtained by HOT2000 are often less than the loads obtained from DOE2 and BLAST, particularly in the "swing" months (spring and fall). At most locations, all three programs are in good agreement in the summer months.

The parametric runs, which varied wall colour, wall insulation level, ventilation rate, thermal mass, and building orientation, produced generally similar results for all three programs. In these cases, the shape of the variation, if not the absolute values, were generally in good agreement.

The preponderance of evidence, based on the results of comparison with DOE2 and BLAST, is that heating, and particularly cooling loads, are underestimated by HOT2000 in the swing months at some locations. Other differences seen in the results may well be minimized when the swing month loads are brought into line. Any changes to the HOT2000 internal and solar gain utilization models to correct these loads must be validated for a diverse range of climates.

COMPARAISON/VALIDATION DU PROGRAMME HOT2000 PAR RAPPORT AU PROGRAMME AMÉRICAIN BLAST 3.0

Résumé

Le présent travail a été entrepris dans le but de comparer les résultats du programme BLAST 3.0 avec ceux d'une étude antérieure, "Comparaison/validation du programme HOT2000 par rapport au programme américain DOE2.1D", et avec ceux d'une version plus récente, HOT2000 (6.03i).

Des modèles de bâtiment élaborés pour l'étude précédente, y compris de simples structures en forme de "boîte" et un modèle relativement réaliste d'une petite maison, ont été préparés pour le programme BLAST. Un ensemble de 15 fichiers de données météorologiques a été produit par traitement à l'aide du programme BLAST. Des ensembles d'essais ont été effectués pour chaque modèle en vue d'étudier l'effet exercé sur les charges de chauffage et de refroidissement par le climat ou la variation de plusieurs paramètres des bâtiments.

Les résultats de cette étude montrent que pour la série Res10, les différences entre les charges de chauffage annuelles des programmes BLAST et HOT200 sont généralement inférieures aux charges obtenues avec le programme DOE 2.1D. Les charges de refroidissement annuelles obtenues avec le programme HOT2000 sont en moyenne d'environ 10 % inférieures aux charges correspondantes calculées par les programmes DOE2 et BLAST.

Les charges de chauffage et de refroidissement mensuelles obtenues avec le programme HOT2000 sont souvent inférieures aux charges obtenues avec les programmes DOE2 et BLAST, particulièrement pendant les mois de "transition" (automne et printemps). Pour la plupart des endroits, les résultats obtenus avec les trois programmes en ce qui a trait aux mois d'été présentent une bonne compatibilité.

Les essais paramétriques effectués avec les trois programmes, dans lesquels on faisait varier la couleur des murs, le degré d'isolation des murs, le taux de ventilation, la masse thermique et l'orientation du bâtiment, ont généralement donné des résultats similaires. Dans ces cas, le mode de variation, sinon les valeurs absolues, présentaient généralement une bonne compatibilité.

L'élément qui ressort nettement de la comparaison avec les programmes DOE2 et BLAST est que les charges de chauffage, et particulièrement les charges de refroidissement, sont sous-estimées par le programme HOT2000 pendant les mois de transition pour certains endroits. D'autres différences observées dans les résultats pourraient bien être réduites lorsque les charges des mois de transition seront ramenées au niveau approprié. Tous changements apportés aux modèles d'utilisation du gain interne et solaire du programme HOT2000 en vue de corriger ces charges doivent être validés pour une gamme variée de climats.

1.0 Introduction

A previous study, "HOT2000 Program Comparison/Validation with U.S. DOE2.1D Computer Program", UNIES Ltd., Nov. 1992, compared HOT2000 with DOE 2.1D. Since that work was done, a version of BLAST 3.0 has been obtained, and a number of minor changes have been made in HOT2000.

The BLAST computer program is developed and maintained by the U.S. Army Construction Engineering Research Laboratory in Champaign, IL. BLAST is widely recognized and used for detailed hourly modelling of building energy systems.

The current study was undertaken to provide further validation for HOT2000, and to arbitrate differences noted in the previous studies. General conclusions from the previous comparisons of DOE2 and HOT2000 were as follows:

1) HOT2000 estimates lower cooling loads in the "swing" months.
2) The variation of cooling loads with forced ventilation rate estimated by HOT2000 appear to be of a different character than the variation estimated by DOE2.1D.
3) The effect of thermal mass on cooling loads is not the same. In DOE2, increasing thermal mass decreases the loads in the "swing" months, and slightly increases the loads in the summer months. In HOT2000, increasing thermal mass decreases the cooling loads in all months.

2.0 Weather Data

The BLAST program has a separate weather data processor (WIFE) to prepare files in "BLAST" format for use in simulations. The weather processor can accept data in a variety of ASCII formats, including TRY and TMY format.

A set of TRY and TMY files was obtained from AcroSoft International Inc., and processed using the WIFE (Weather Information File Encoder) program. Available output reports were used to validate the data by comparison with outputs from previous DOE weather processor runs. Only minor deviations were noted, probably resulting from round-off errors.

Previously prepared DOE2 and HOT2000 weather files were used without modification.

The current version of the BLAST program does not include outputs for the solar radiation falling on vertical surfaces. However, the source code for the BLAST program and the WIFE program had been obtained along with the executables.

The BLAST programs are compiled by CERL using the NDP Fortran 32 bit compiler, so the data files produced by the BLAST and WIFE programs can not be read by programs compiled using some other compiler. The Microsoft Fortran compiler was used (the only one available to this study) to prepare a "local" version of the WIFE program. This local WIFE was then used with the ASCII TMY and TRY files to prepare local WIFE format files.

A small program was then prepared to process these hourly WIFE files to estimate solar radiation on vertical surfaces facing South, East, North, and West. The WIFE files include hourly beam, diffuse, and ground reflected solar radiation, other hourly weather parameters, and daily values for the "equation of time", and the solar declination. The hourly solar radiation on a vertical surface is estimated using the methods found in the text, "Solar Energy Thermal Processes", by Duffie and Beckman.

Figures 1 and 2 show the results of these calculations at Amarillo and Bismarck, for January 1 and July 1. These calculations are based on the "real" weather data, so the amounts shown vary with cloud cover at each hour. For example, at Amarillo, the East solar radiation is much larger than the West solar radiation on January 1, but about the same on July 1. The large decrease in beam solar radiation after noon on January 1 probably results from increasing cloud cover. At Bismarck, the West solar radiation is greater than the East solar radiation on July 1. The South facing solar radiation at Bismarck is quite large in January, and much less in July. Again, at Bismarck, it is interesting to note the increase in the North solar radiation just at sunset, when the sun can "see" this surface at that time of day.

In addition to the hourly calculations, the vertical solar radiation was summarized monthly for comparison with the data used by DOE2 and HOT2000, Figures 3 and 4. Generally, the WIFE estimates of South vertical solar radiation are less than, and the estimates of North radiation are greater than the corresponding estimates given by DOE2.1D.

The results for the East and West directions are more difficult to compare, because in HOT2000, solar radiation is assumed to be symmetric about the North/South axis (i.e. East=West, NE=NW, SE=SW). The estimates given from the WIFE files show the magnitude of the difference between the East and West

Solar radiation, in the order of 15%. The HOT2000 estimates are closer to the East estimates at Amarillo, and closer to the West estimates from WIFE at Bismarck.

These results generally indicate agreement between the two programs within approximately 15%. It must be stressed however, that the "WIFE" estimates given here do not necessarily correspond to the values used in the BLAST program. Rather, these estimates are our interpretation of how such values might be derived in BLAST. Only a more complete inspection of the BLAST code can verify that this interpretation is precise.

3.0 "Box" Runs

The "Box" runs are simple structures with no windows or internal gains. Box01 has a roof, and Box03 consists of only 4 walls.

Box01 was run at Amarillo, Tx, and at Bismarck ND, Figure 5. In both cases, the BLAST models estimate lower heating loads in the coldest months.

Box03 was run at Bismarck ND, Figure 6. The top graph shows the monthly space heating load for the HOT2000 default wall colour (Absorptance = 0.4). The bottom graph shows the annual heating load for a range of wall colours. All programs appear to exhibit a similar characteristic variation.

Figure 7 shows the results of a set of runs to vary the wall R-value. The top graph shows the monthly heating loads for an R40 wall. Note 1/R is used as the x-axis in the bottom graph. Each program has a slightly different slope, so the difference in heating load increases as the R-value decreases.

4.0 Res10 Runs

Building Res10 is a typical bungalow, with double glazed windows of varying sizes in 4 directions, an attic, internal gains, and a forced ventilation rate of 0.25 ACH. As in previous studies, this building was run for the complete set of 15 test weather locations. Monthly results for this series are presented in Figures 8a - 8h.

Generally, these results indicate that HOT2000 estimates lower cooling loads in the "swing" months at many (but not all) locations. The differences between programs tend to be less at locations which have a continental climate, eg. Bismarck, Fairbanks, Glasgow, Minot, Rochester. Some locations tend to be very "noisy", with relatively large differences in monthly heating and cooling loads between programs, eg. Arcata, Astoria, Denver, Seattle.

Annual summaries are presented in Figure 9, and Table 1.

Table 1. Series Res10

	Annual Energy Load (GJ)					
	Cooling			Heating		
	DOE 2.1D	BLAST	HOT2000	DOE 2.1D	BLAST	HOT2000
Amarillo	15.56	16.53	13.51	9.90	8.88	8.47
Arcata	1.08	2.70	0.77	9.43	6.58	7.81
Astoria	2.39	3.58	1.66	14.36	11.39	11.95
Bismarck	8.79	9.36	7.61	34.31	31.63	32.57
Boston	8.84	9.37	8.42	17.63	15.65	15.90
Denver	9.97	12.19	8.34	14.44	12.62	13.68
Fairbanks	3.19	3.69	3.12	57.02	54.40	55.45
Glasgow	8.48	9.47	7.58	28.96	26.66	27.45
Laredo	33.23	32.29	31.52	1.79	1.21	0.19
Miami	36.00	34.48	36.48	0.17	0.09	0.00
Minot	7.65	8.23	6.52	31.38	29.31	29.29
Rochester	7.67	8.45	6.59	24.90	22.21	22.26
Seattle TRY	3.43	4.82	2.79	16.72	13.59	14.48
Seattle TMY	4.33	5.58	3.10	16.04	12.97	13.56
Washington	11.78	12.82	10.99	14.58	12.47	12.13
	10.83	11.57	9.93	19.44	17.31	17.68

At most locations, it is evident from the comparisons of monthly results, that in the swing months the HOT2000 heating and cooling loads tend to be less than the corresponding loads calculated by DOE2 and BLAST.

5.0 Res10 Ventilation Runs

Model Res10 was run at Amarillo, TX for varying ventilation rates, Figure 10. This series was extended to extremely high ventilation rates (4 ACH). For annual heating loads, the increase in load with ventilation rate is very similar for all 3 programs.

For annual cooling loads, the DOE2 and BLAST program results show smaller numeric differences, but the shape of the variation with ventilation rate is more similar between BLAST and HOT2000.

The comparisons of monthly loads at ventilation rates up to 0.5 ACH, are similar to those generally obtained for the 15 city set. However, at the highest ventilation rate, Figure 10c, the heating loads for HOT2000 are significantly higher in the winter months, and lower in the swing months than either BLAST or DOE2.

6.0 Res10 Thermal Mass Runs

Model Res10 was run at Amarillo, TX and Bismarck, ND for the four thermal mass levels available in HOT2000, Figure 11. The annual results indicate that increasing the thermal mass from "A" to "B" level has the greatest effect on the heating and cooling loads. Mass levels greater than "B" have relatively less impact on the loads. Figures 11c and 11d show the monthly cooling loads for DOE2, BLAST, and HOT2000, for each of the four mass levels chosen.

The monthly results show that the effect of thermal mass is similar for DOE2 and BLAST, where increasing thermal mass decreases the load in the swing months, and slightly increases the load in the summer months. For HOT2000, increasing thermal mass decreases the load in all months.

7.0 Res10 House Orientation Runs

In order to investigate the directional sensitivity of the BLAST and HOT2000 models, the house was rotated through a set of 90 degree rotations to point the house South (the base case), East, North, and West. The results of this series are presented in Figures 12 and 13.

Monthly cooling loads are maximized when the house is oriented East/West, but the BLAST program shows East obtains noticeably higher cooling loads than West. HOT2000 shows very slightly higher cooling loads for East, but this is because of the asymmetry in the placement of the windows. These results are generally consistent with the solar radiation data used by the programs, Figure 3.

8.0 Conclusion

BLAST weather files have been prepared using the TMY and TRY data previously used for DOE2 runs. The monthly estimates (based on hourly sums) of solar radiation on vertical surfaces facing South, East, North, and South for the two programs are generally within 15%.

The variation of annual heating loads with wall colour and insulation value are quite similar between BLAST, DOE2, and HOT2000. For these series (BOX03), BLAST and HOT2000 heating loads are generally in closer agreement with each other than with DOE2.

A model of a typical small bungalow (Res10) was used for most of the series of comparison runs. For the 15 city series, the average annual heating loads for DOE2, BLAST, and HOT2000 were 19.4 GJ, 17.3 GJ, and 17.7 GJ, respectively. The monthly results also show that, in most cases, BLAST and HOT2000 heating loads are generally in closer agreement with each other than with DOE2.

The results obtained for cooling loads generally confirm previous findings. The HOT2000 estimates of annual and monthly cooling loads are generally less than those obtained using either DOE2 or BLAST. However, in many locations, the "summer" cooling loads are in good agreement between all three programs. In the swing months, HOT2000 consistently gives smaller (or zero) cooling and heating loads.

There are a number of locations (Arcata, Astoria, Seattle) where the differences between programs vary considerably. In particular months, it is easy to find exceptions to the general observations given above. These variations are probably due to weather data differences, but a detailed study of the hourly results would be needed to confirm this.

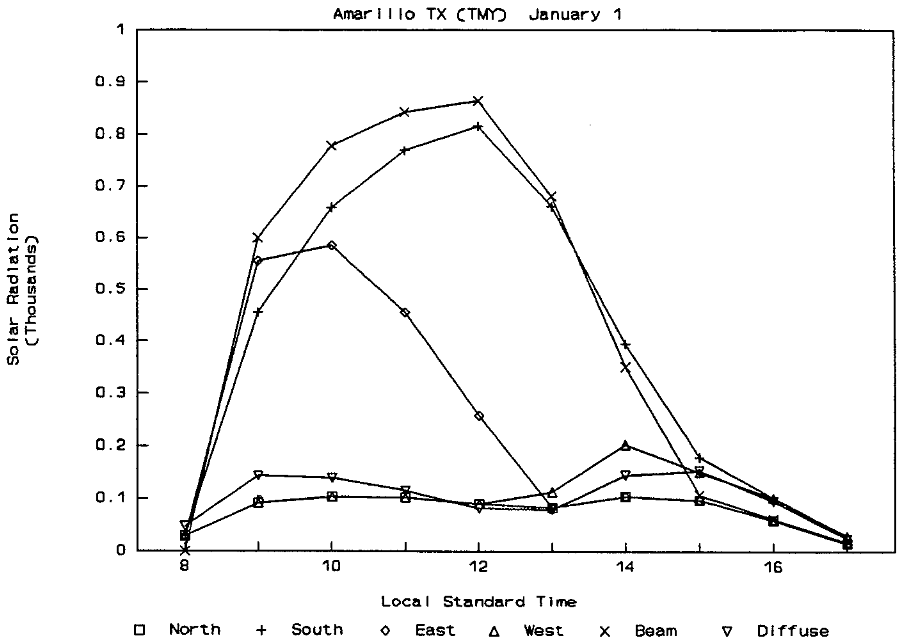
The variation of cooling loads with ventilation rate, and with thermal mass are generally consistent between the three programs, particularly when the apparent underestimates of HOT2000 are taken into account.

Although DOE2 and BLAST agree better in absolute value, the shape of the variation of cooling load with ventilation rate is more similar between BLAST and HOT2000. Particularly at very high ventilation rates, the actual indoor temperature becomes a determining factor in calculating the air change heat loss/gain rate. In previous versions of HOT2000, the indoor air temperature was assumed to be the heating set-point when calculating air change heat loss. In the present version, the indoor air temperature is assumed to be at the heating set-point at low temperatures, equal to the outdoor air temperature above the heating set-point, and the cooling set-point at high outdoor temperatures. For greater precision, this model should be refined to use the balance point temperatures.

The effect of thermal mass in HOT2000 appears to be of a different character than in either BLAST or DOE2. In both BLAST and DOE2, greater thermal mass decreases the cooling loads in the swing months, and slightly increases the cooling loads in the summer months. In HOT2000, increasing thermal mass decreases the cooling load in all months.

It is likely that the apparent problems in the HOT2000 calculation of both cooling and heating loads in the "swing" months are related to the underlying models for utilization of internal and solar gains, as well as the effects of thermal mass.

It is important to emphasize that any new models be validated for a wide range of climates, and compared with as many different hourly programs as is practical.



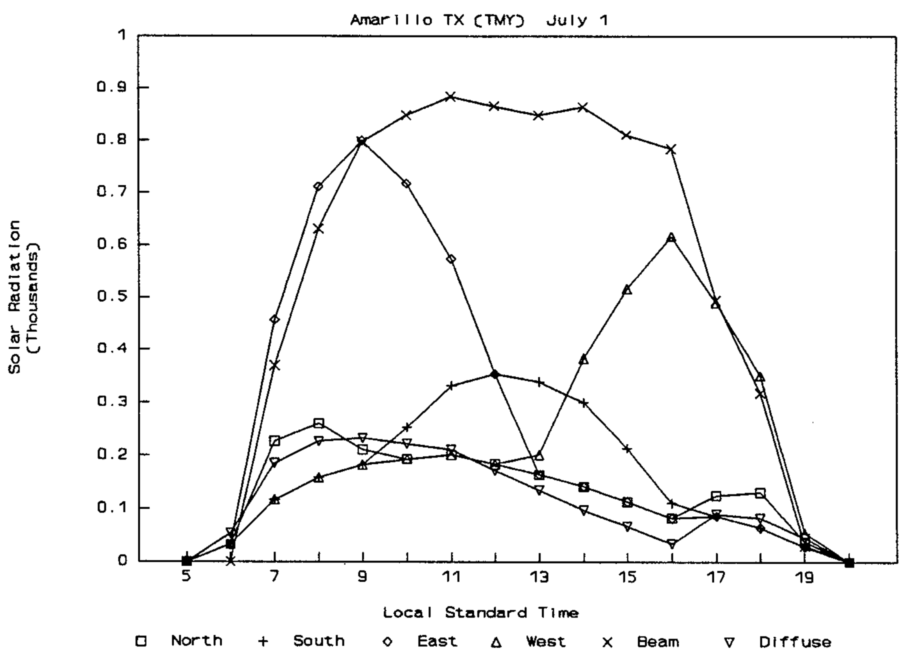
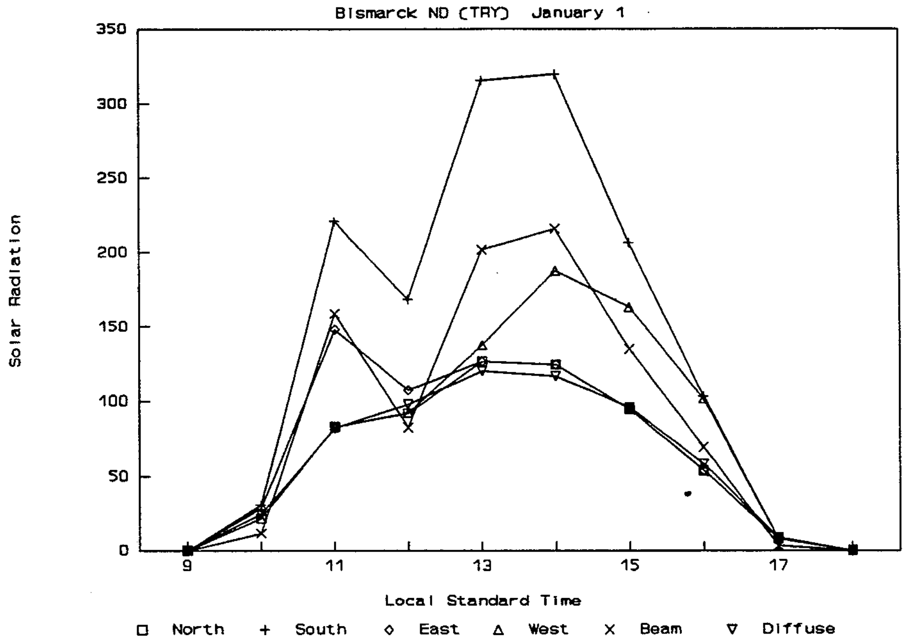


Figure 1. Hourly Solar Radiation - Amarillo TX



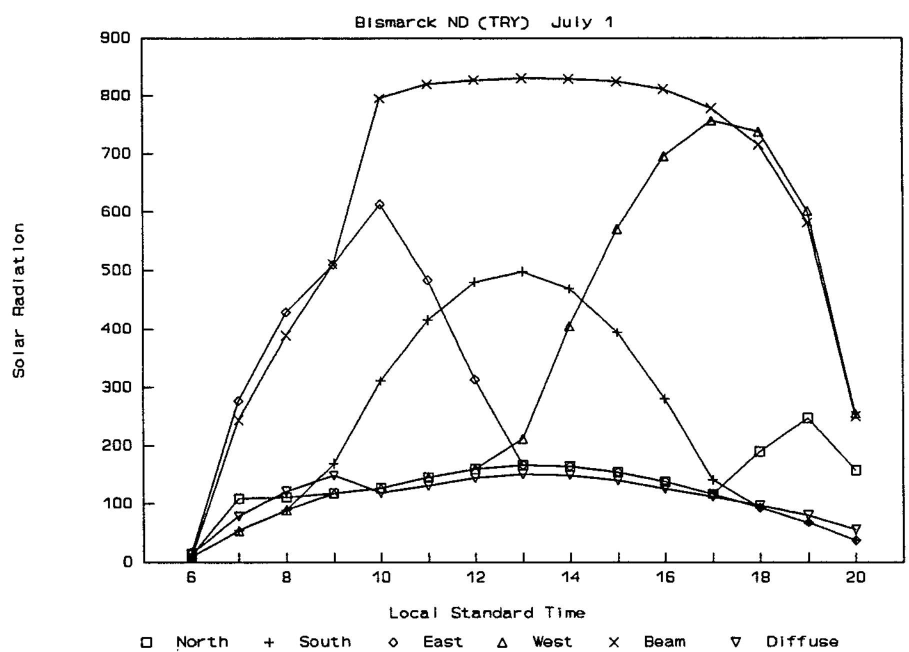
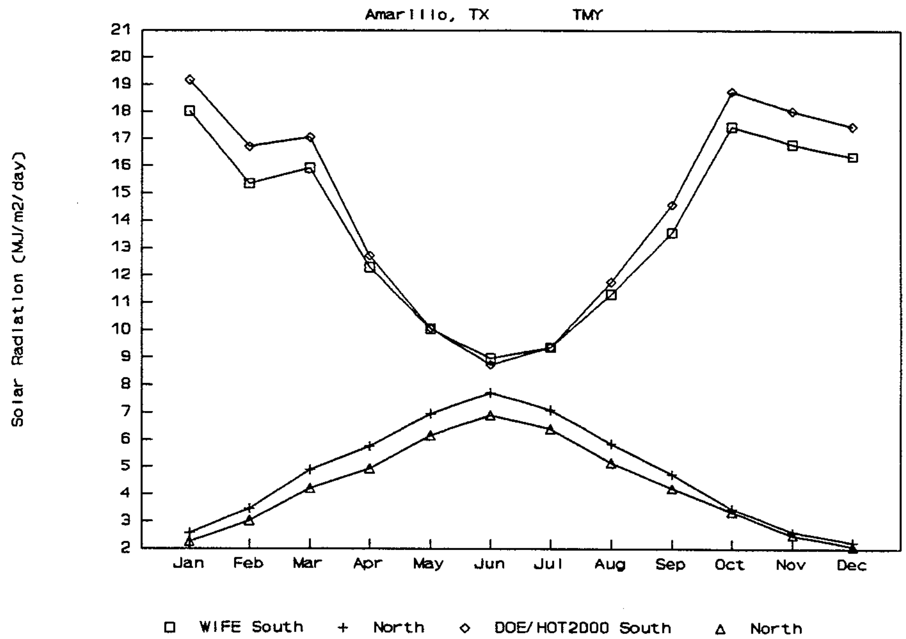


Figure 2. Hourly Solar Radiation - Bismarck ND



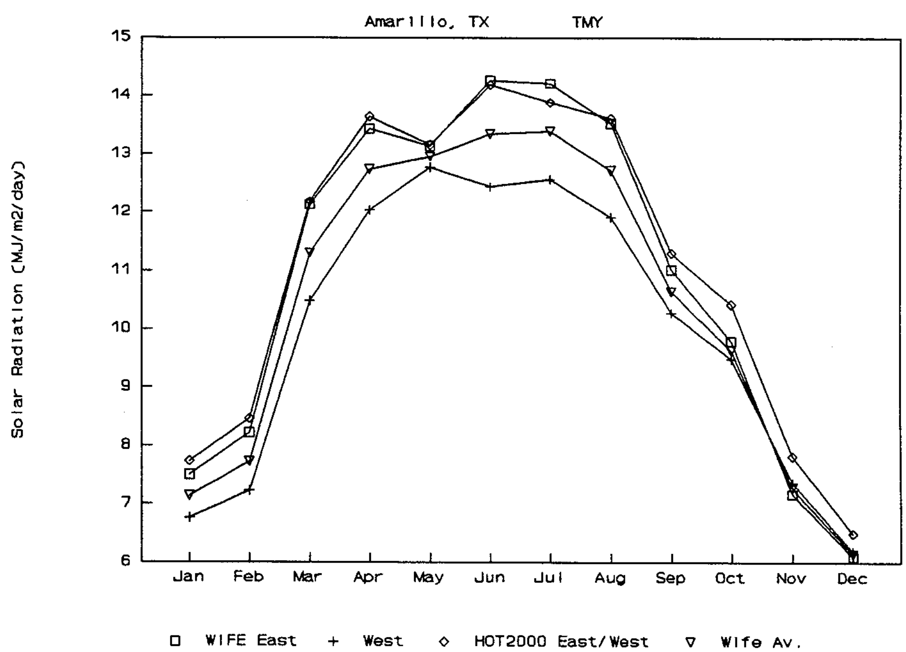
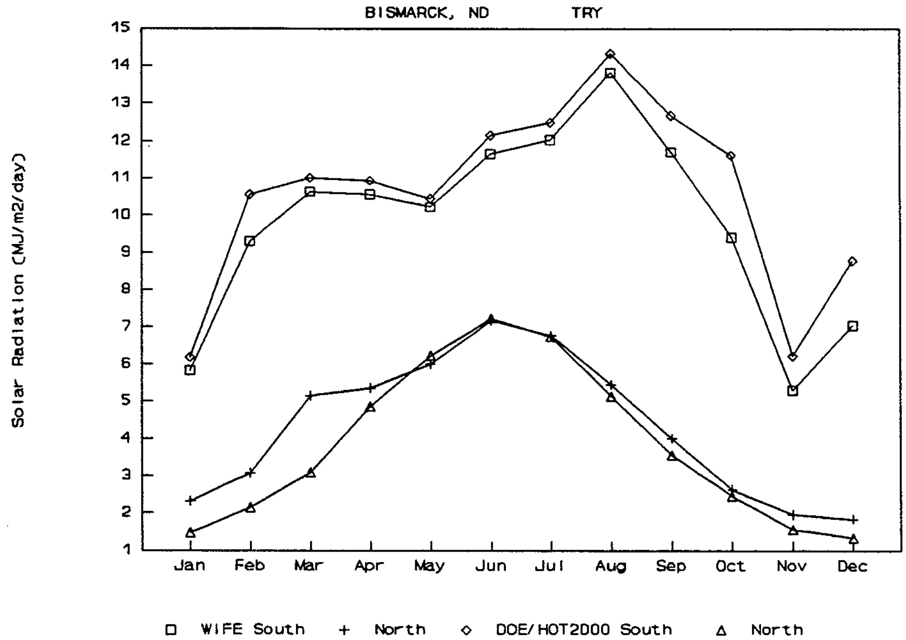


Figure 3. Monthly Solar Radiation - Amarillo TX



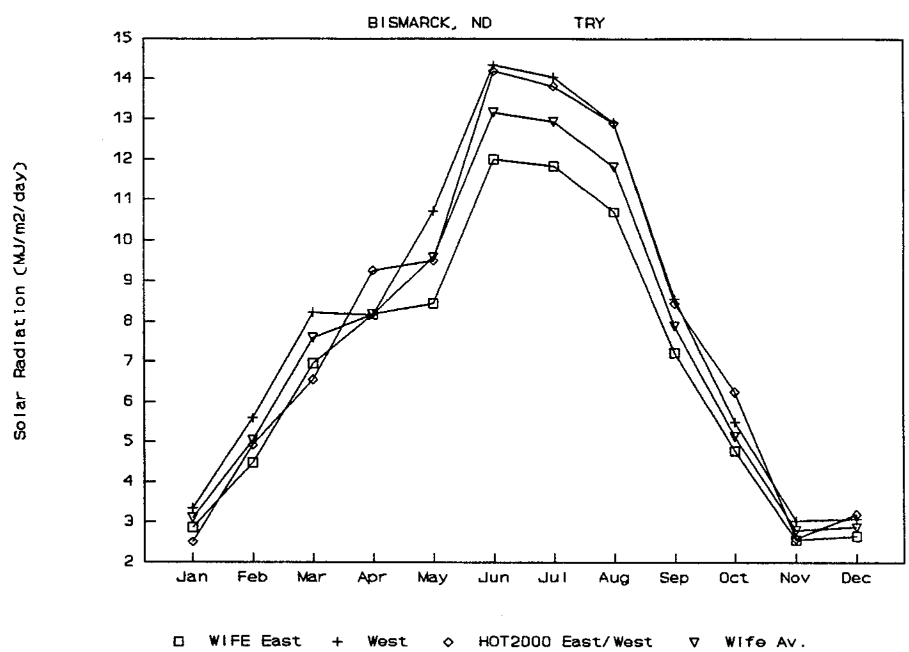


Figure 4. Monthly Solar Radiation - Bismarck ND

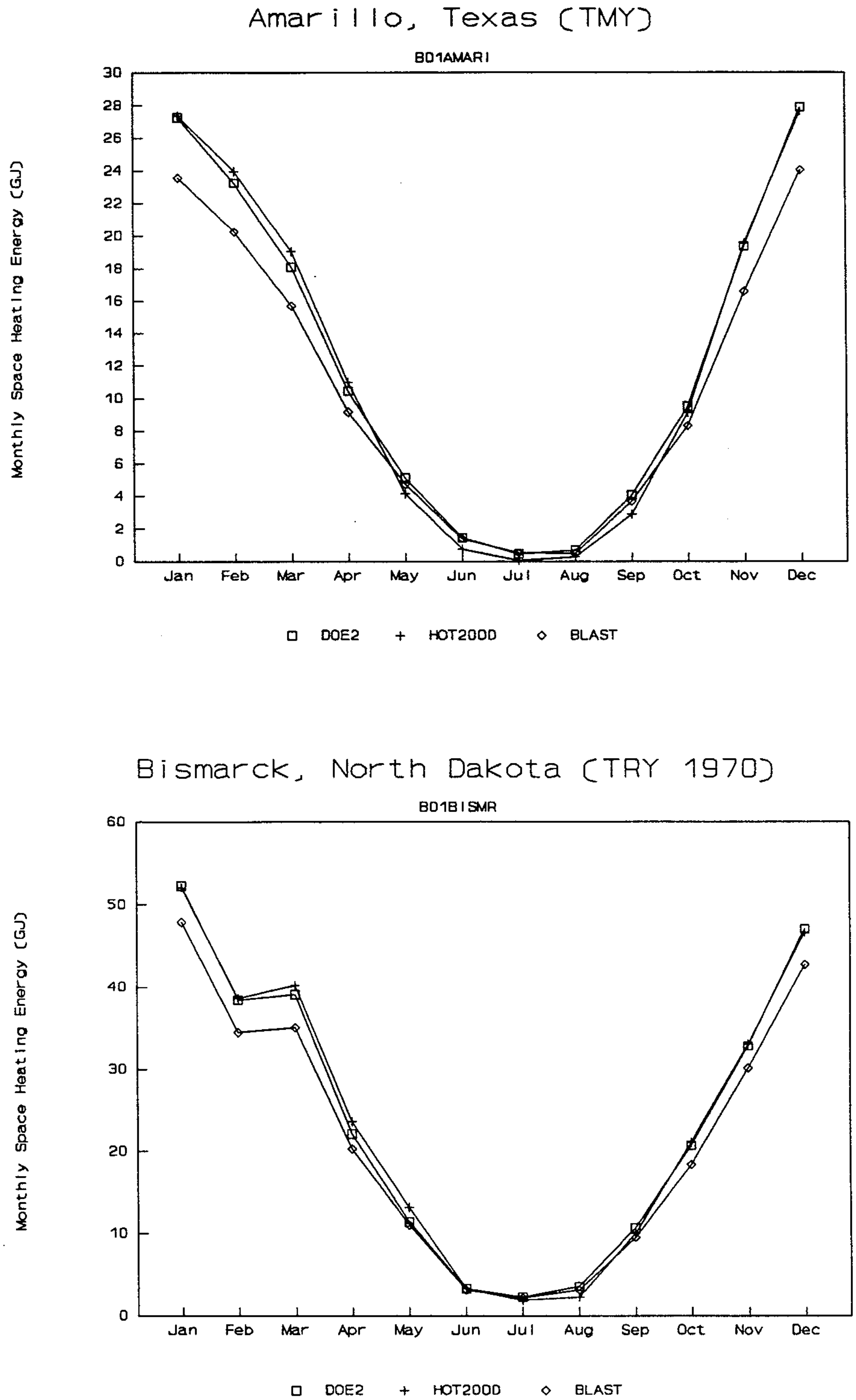


Figure 5. Series Box01

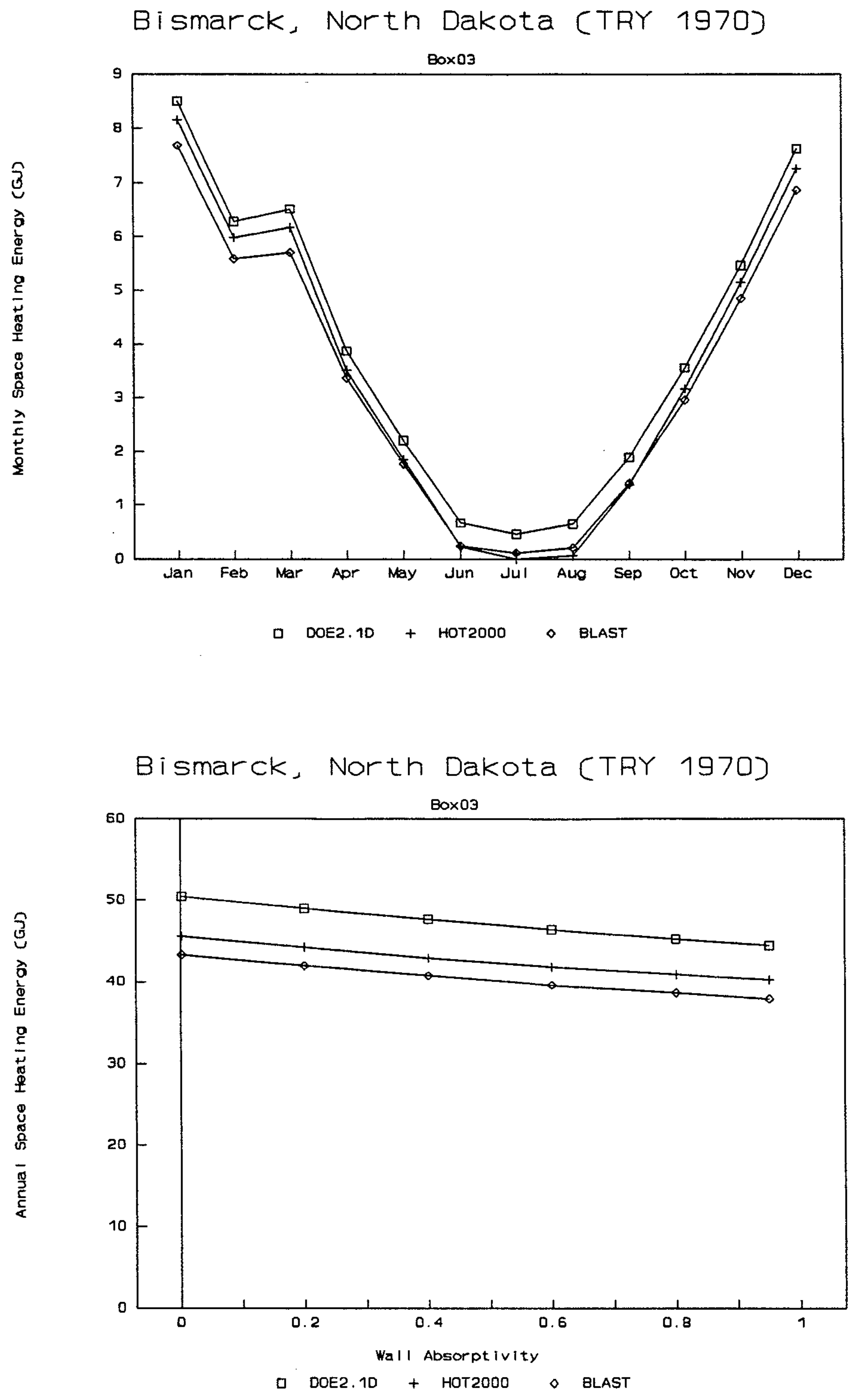
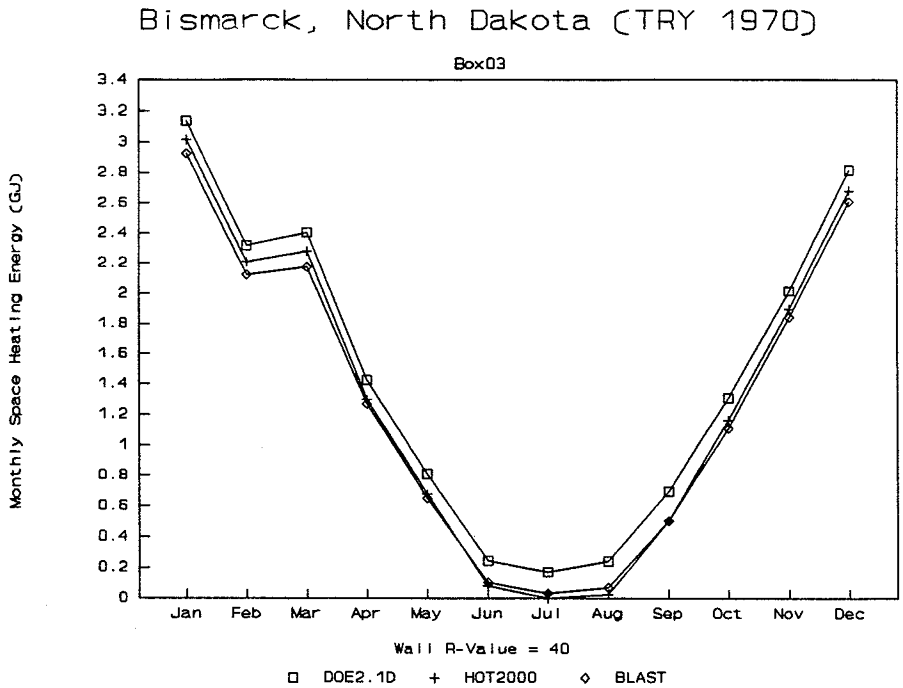


Figure 6. Series Box03 - Wall Colour



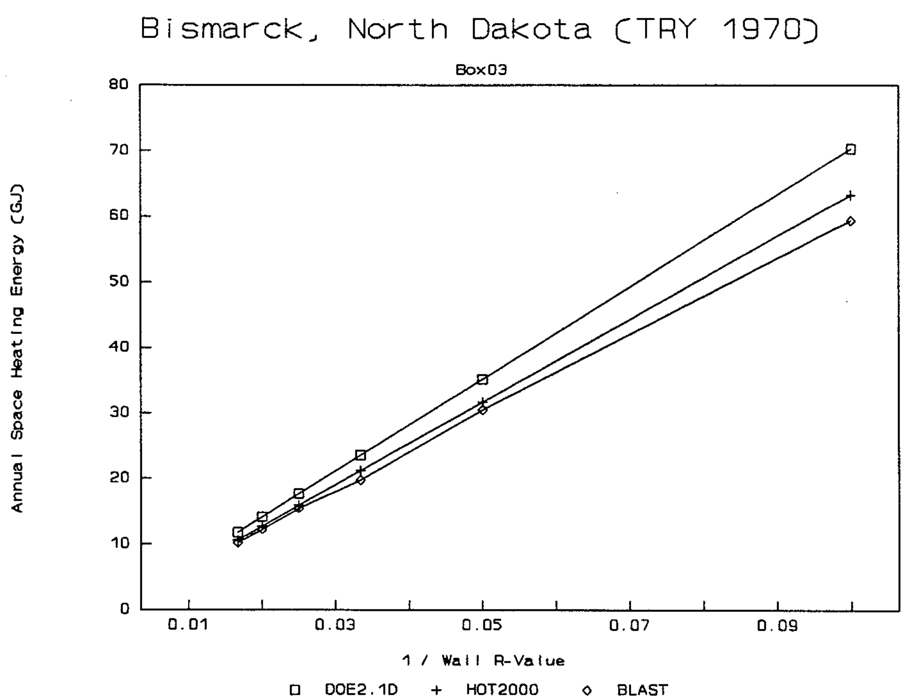
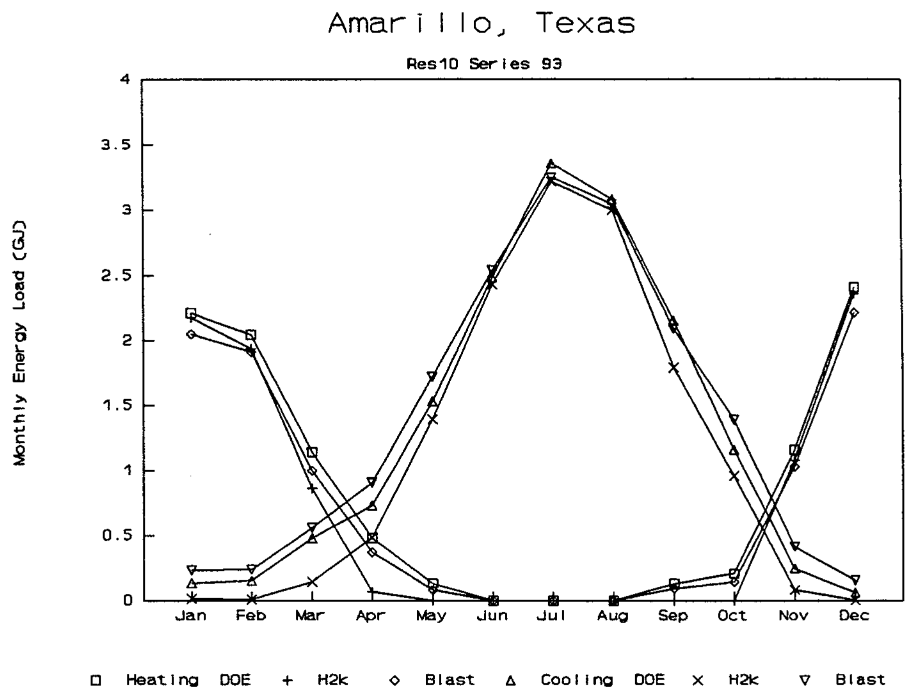


Figure 7. Series Box03 - Wall R-Value



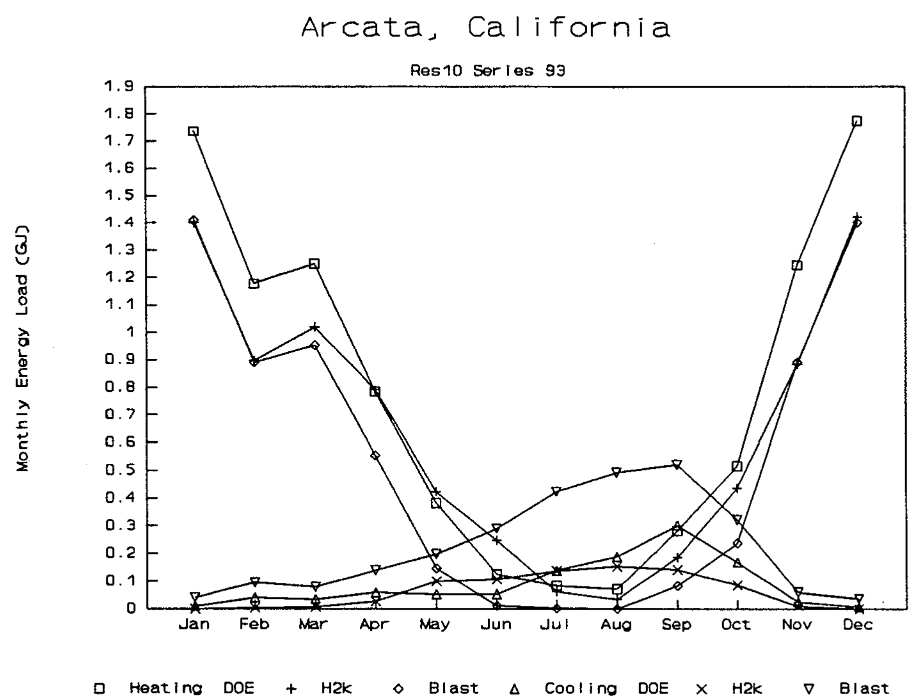
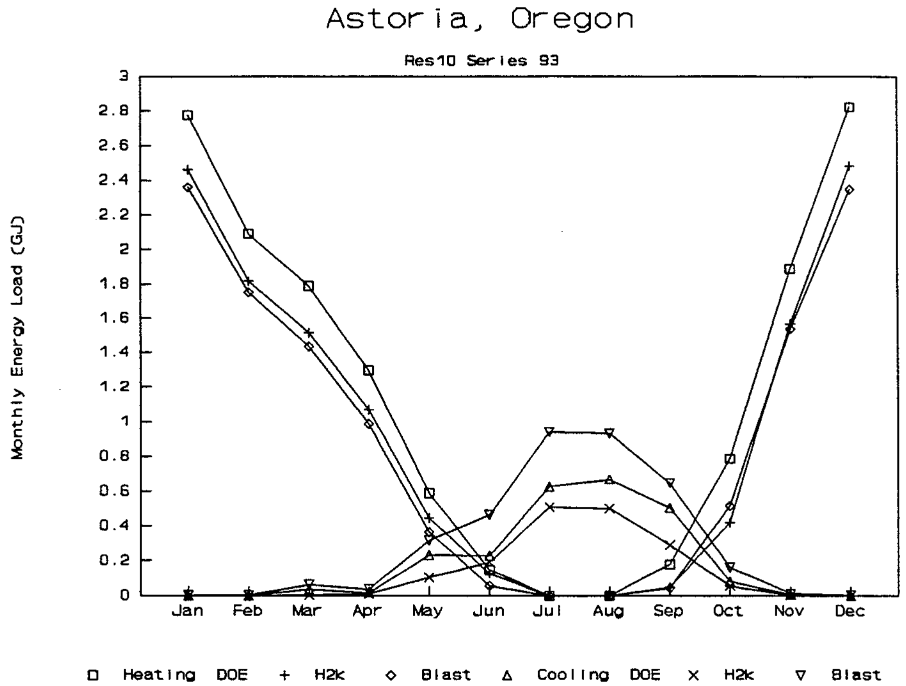


Figure 8a. Series Res10 (Page 1 of 8)



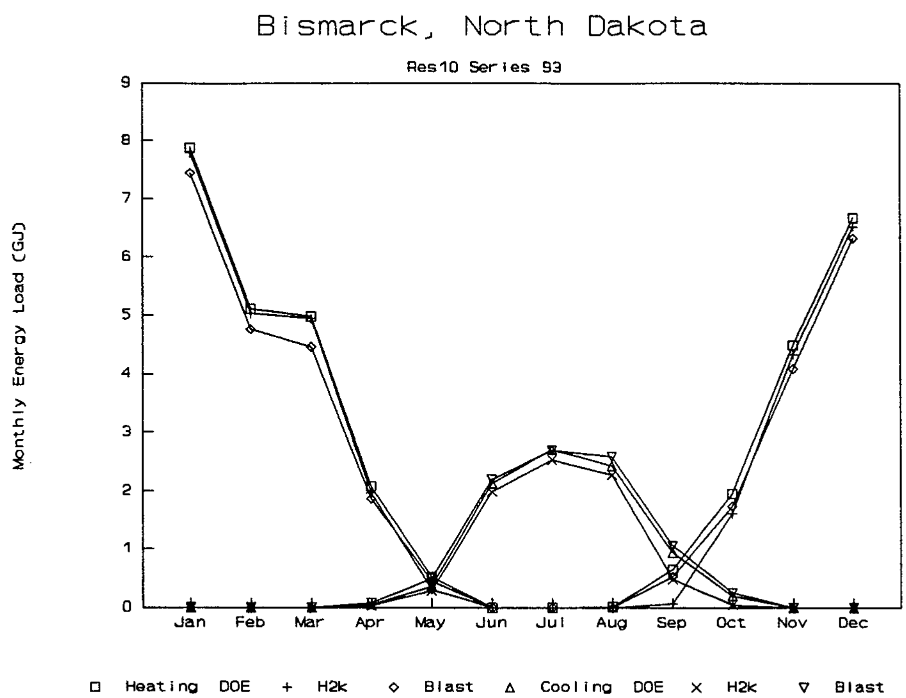
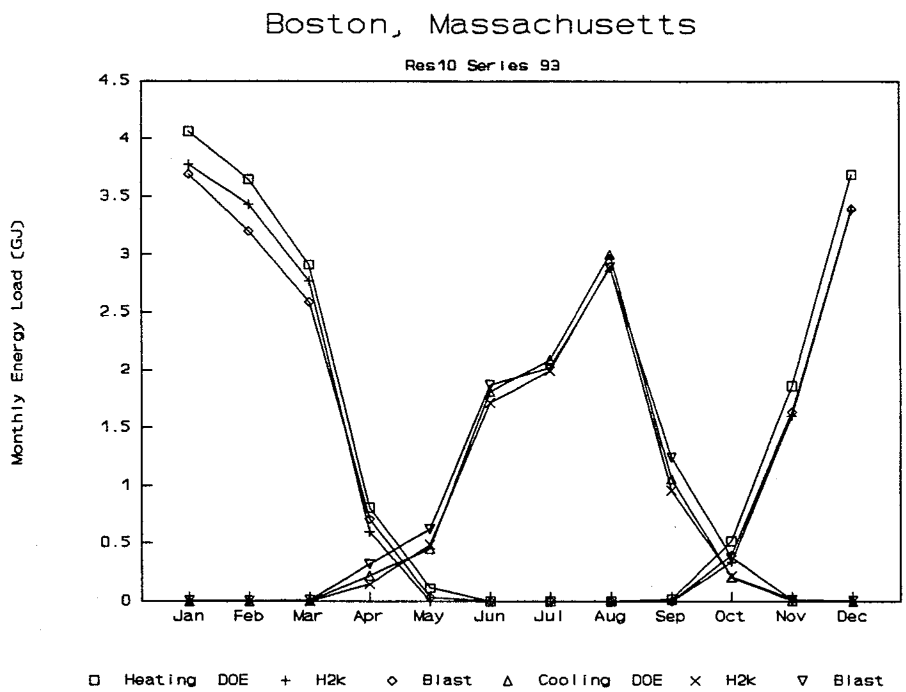


Figure 8b. Series Res10 (Page 2 of 8)



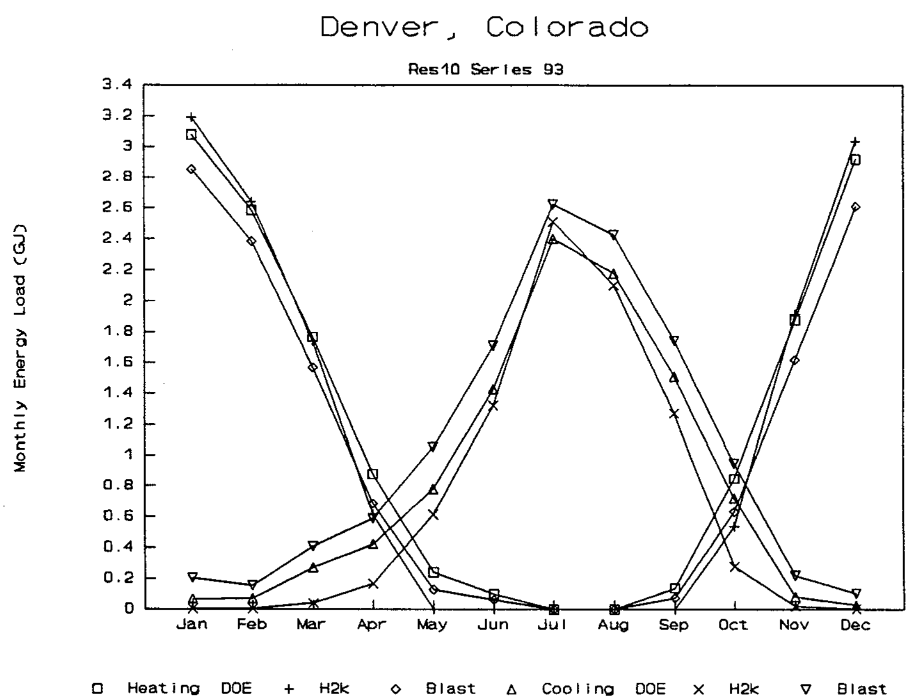
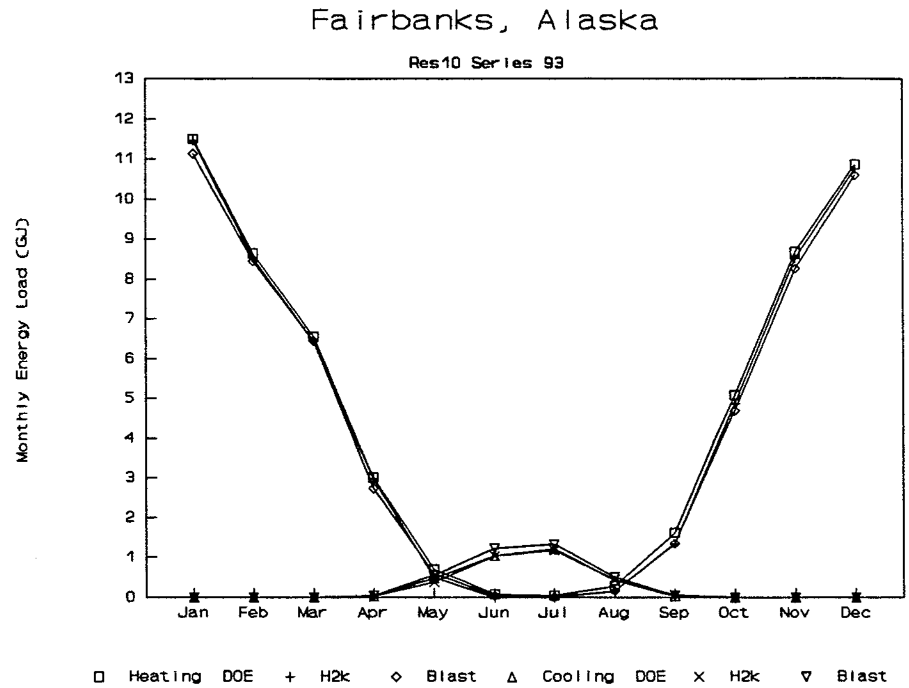


Figure 8c. Series Res10 (Page 3 of 8)



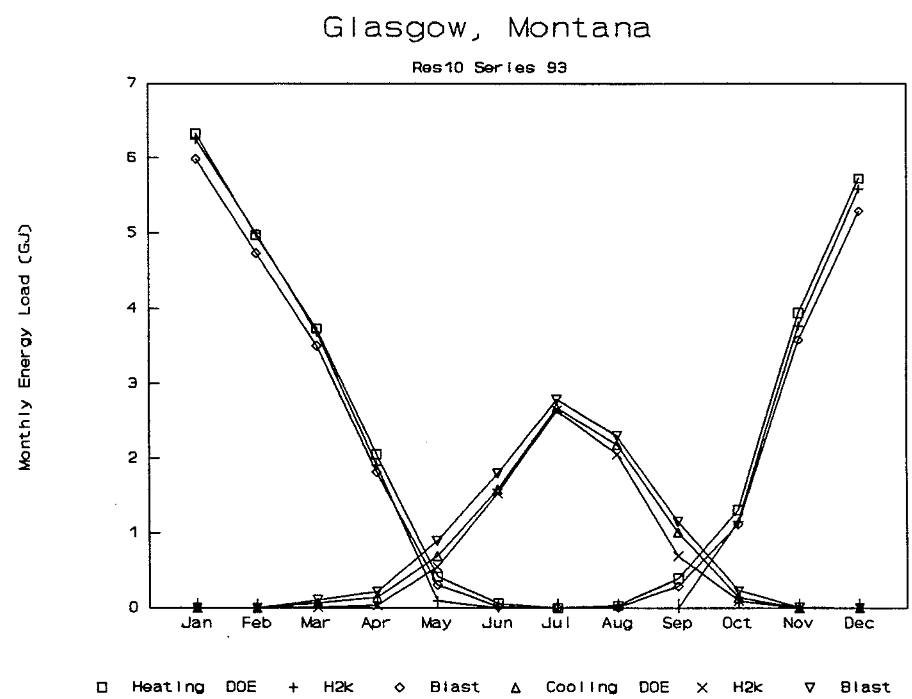
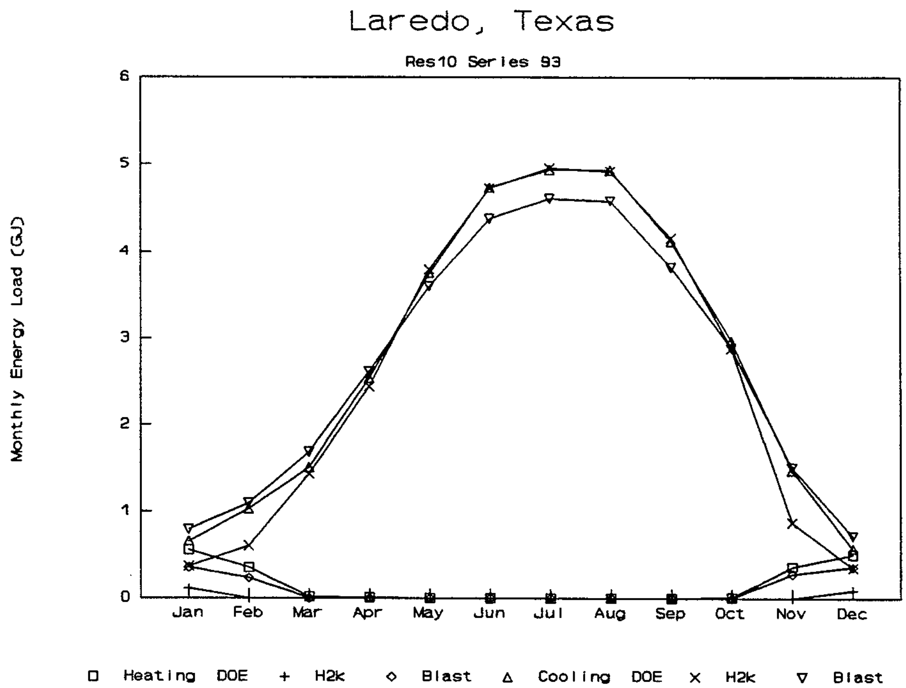


Figure 8d. Series Res10 (Page 4 of 8)



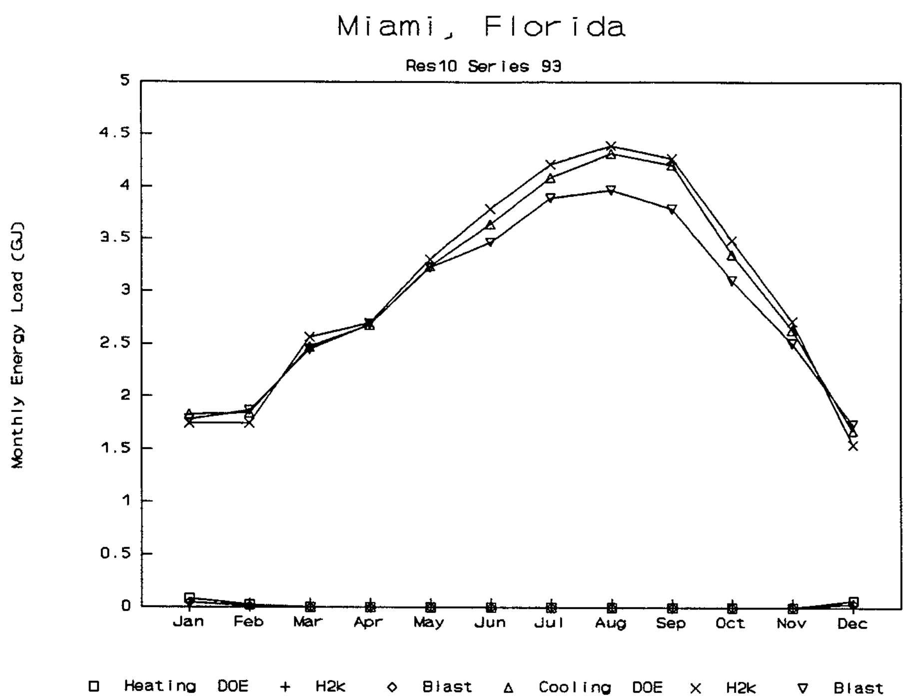
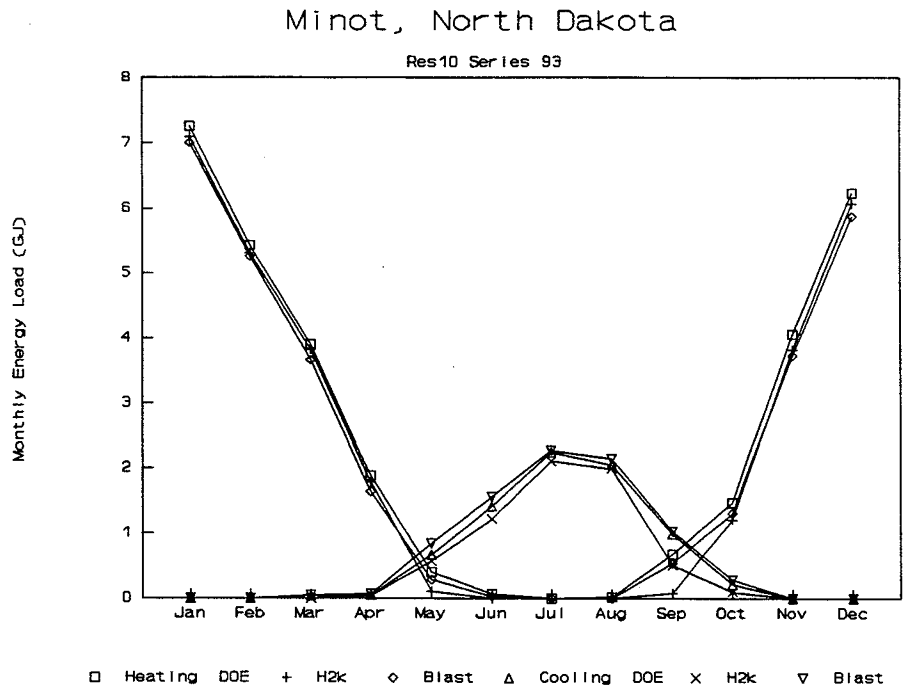


Figure 8e. Series Res10 (Page 5 of 8)



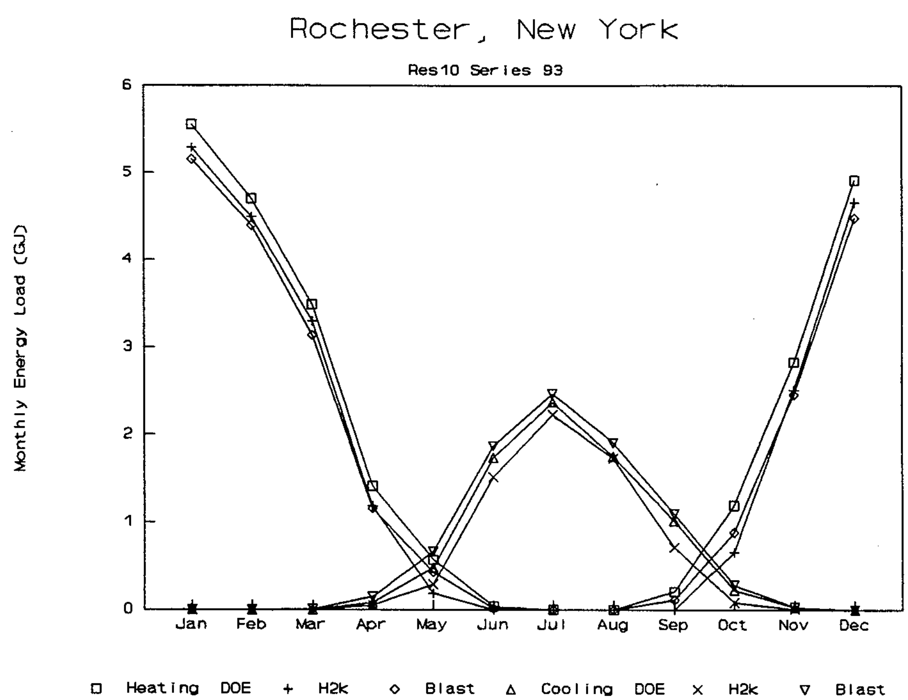
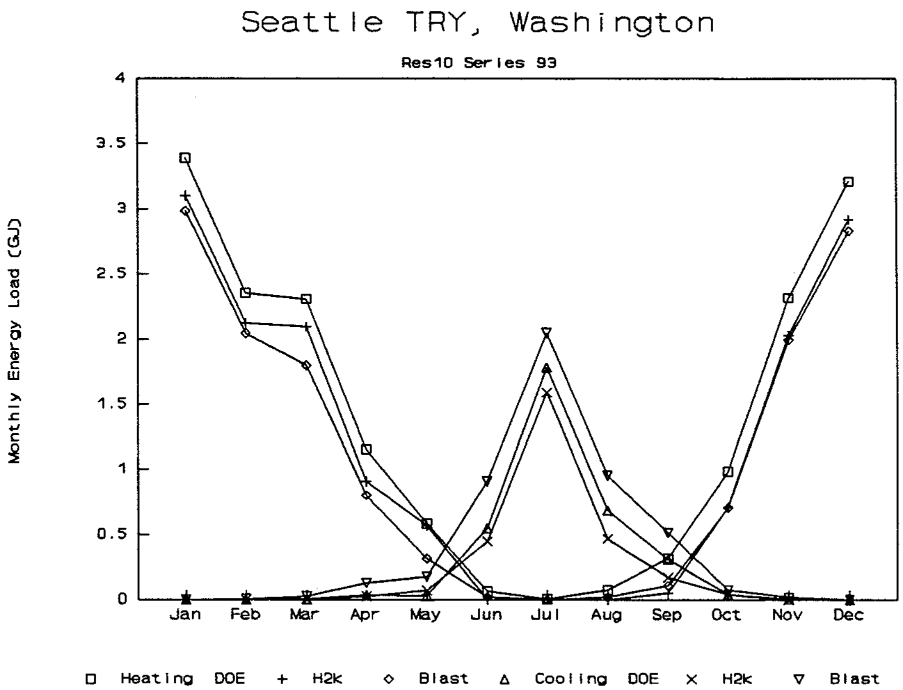
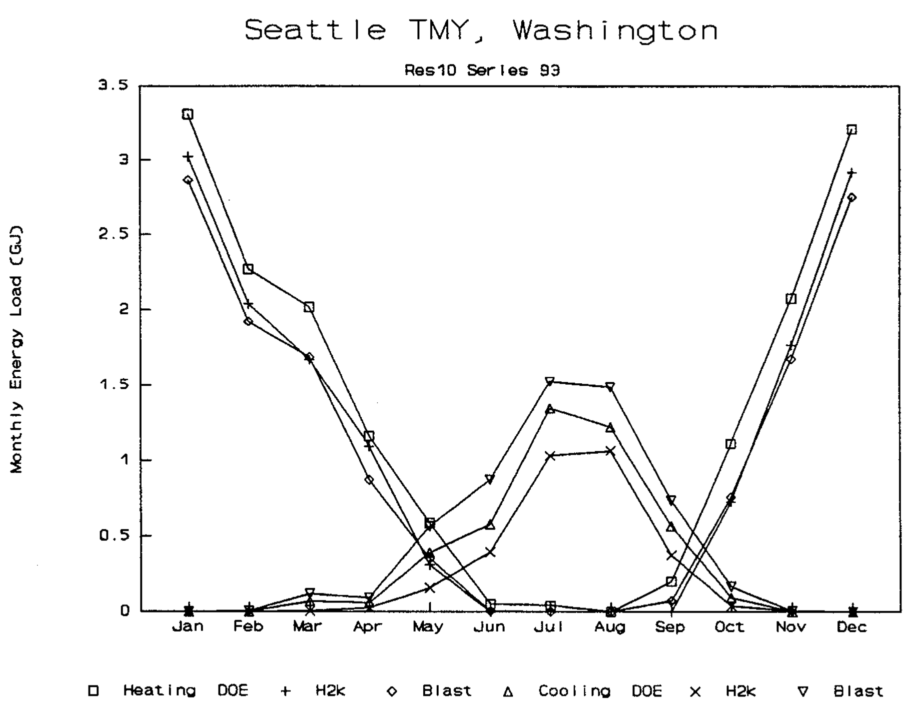


Figure 8f. Series Res10 (Page 6 of 8)





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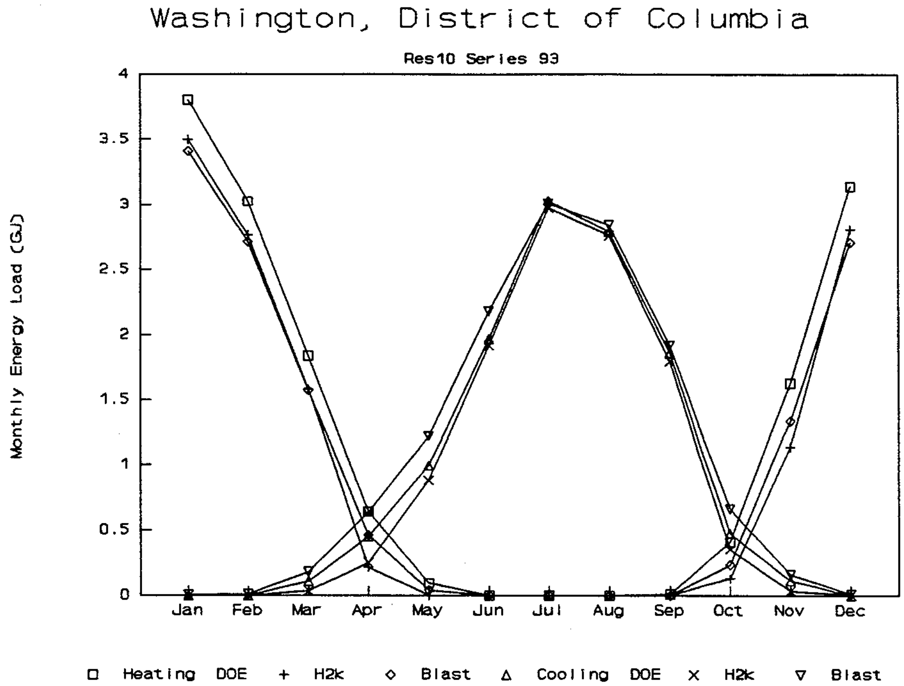
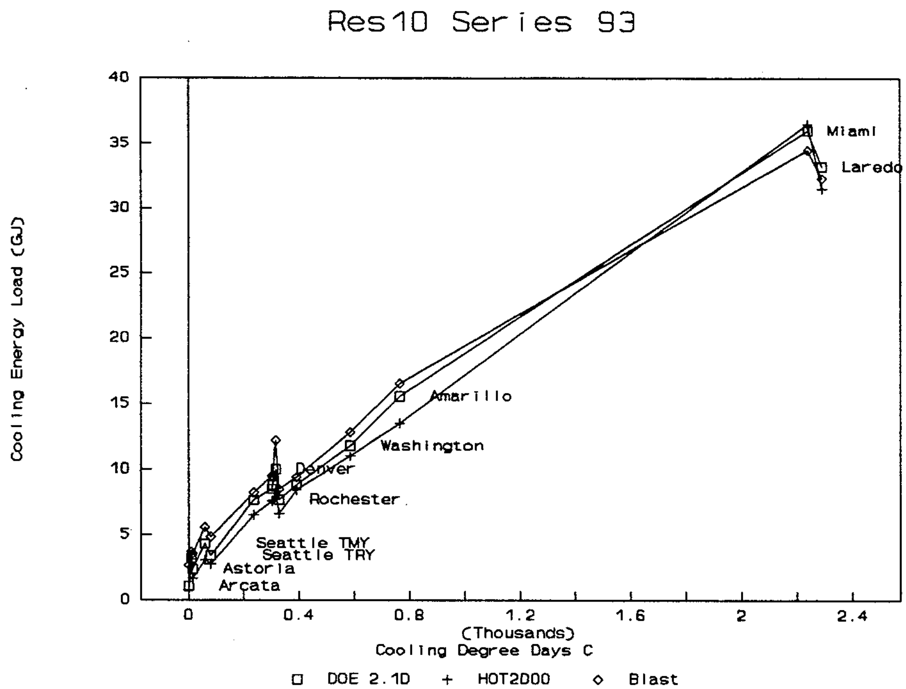


Figure 8h. Series Res10 (Page 8 of 8)



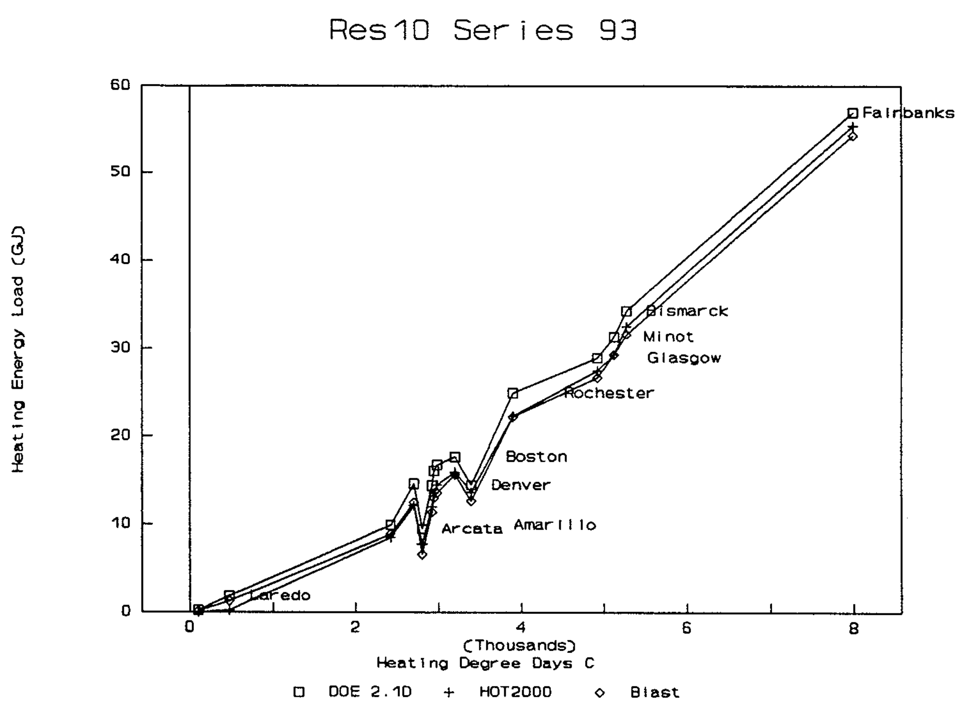
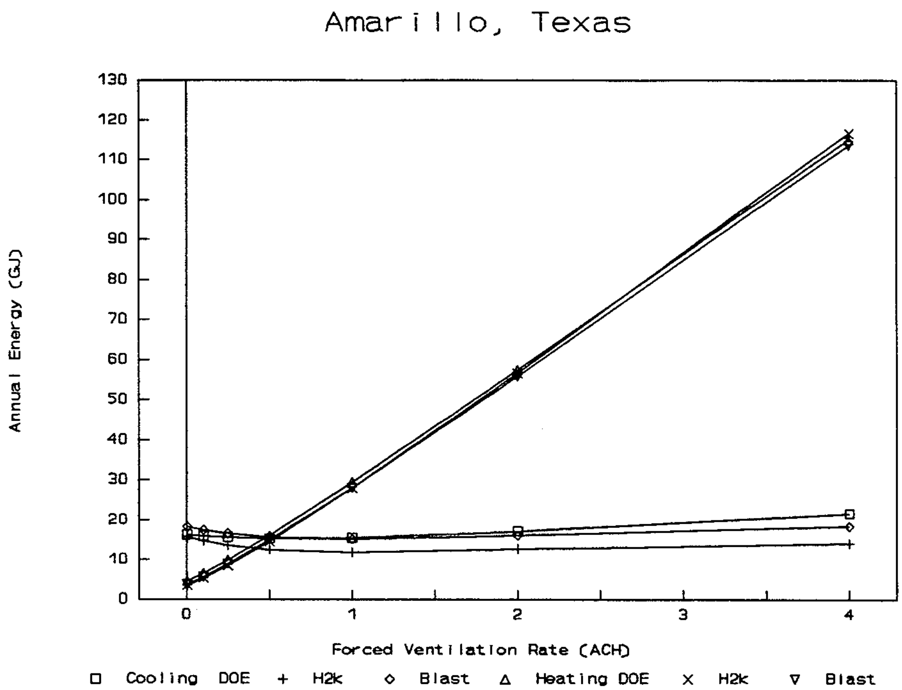


Figure 9. Series Res10 Summary



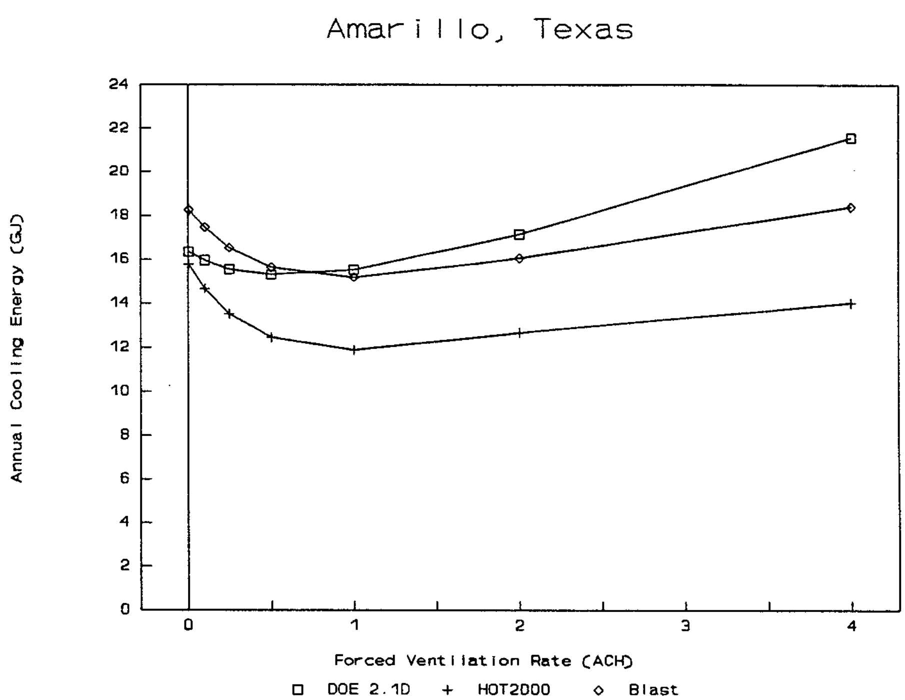
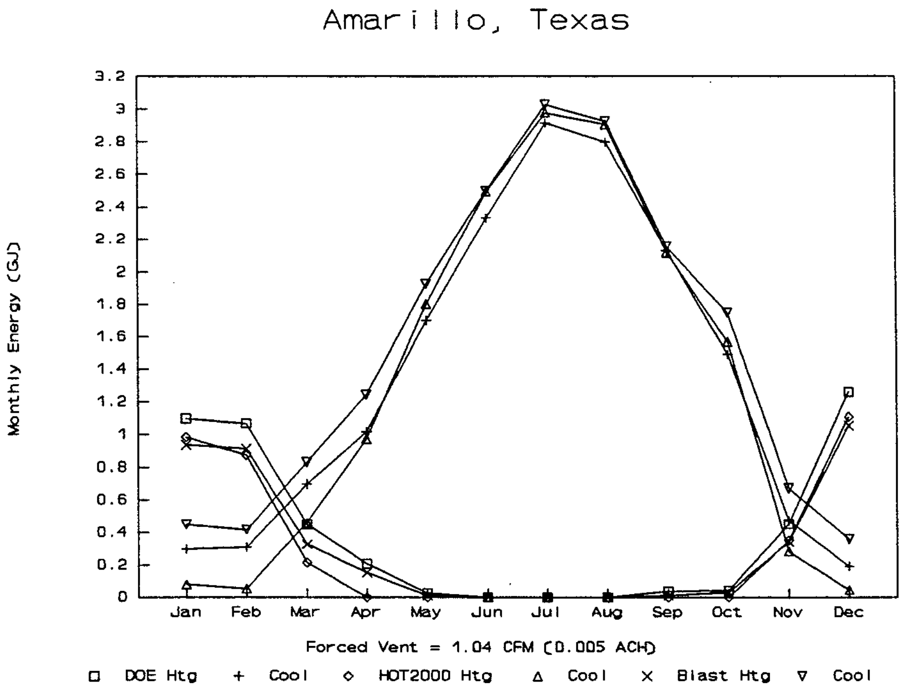


Figure 10a. Series Res10 Ventilation Rate



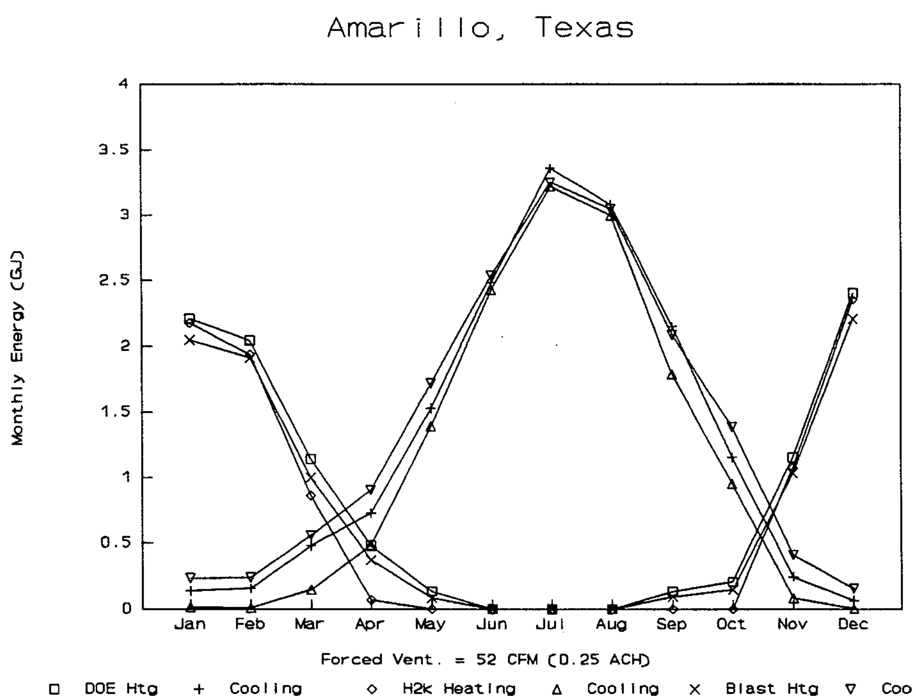
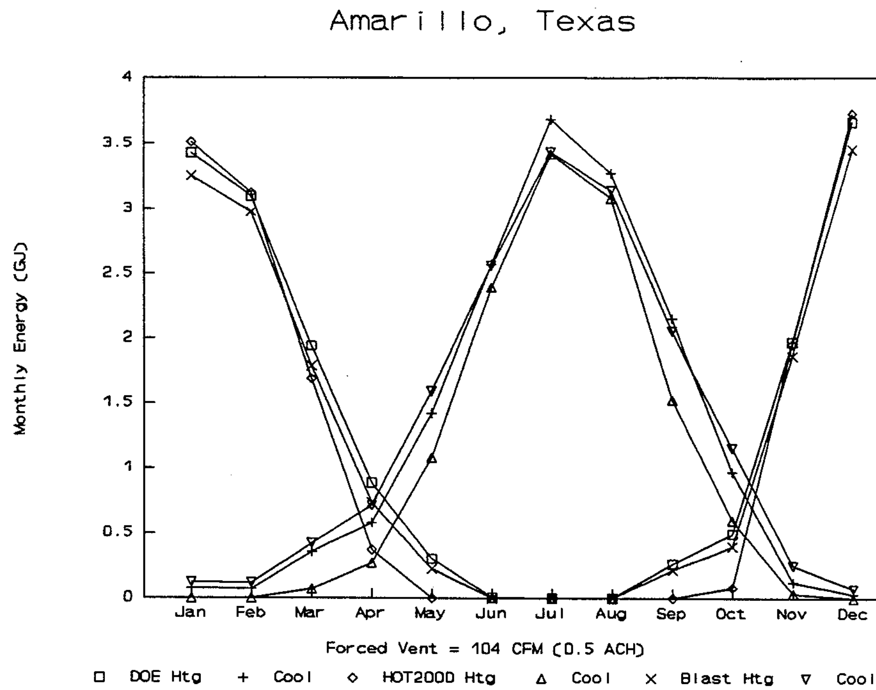


Figure 10b. Series Res10 Ventilation Rate



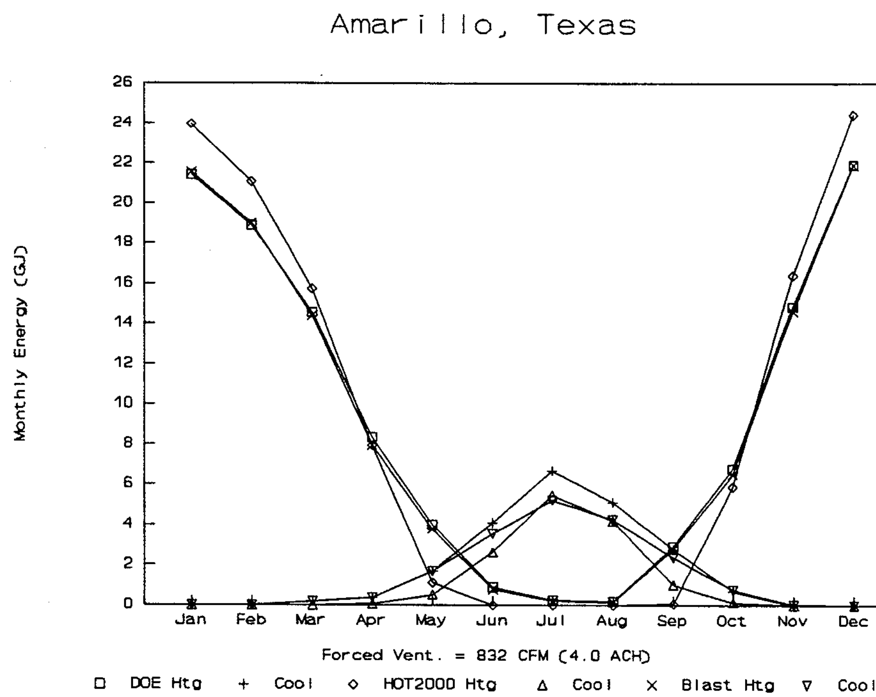
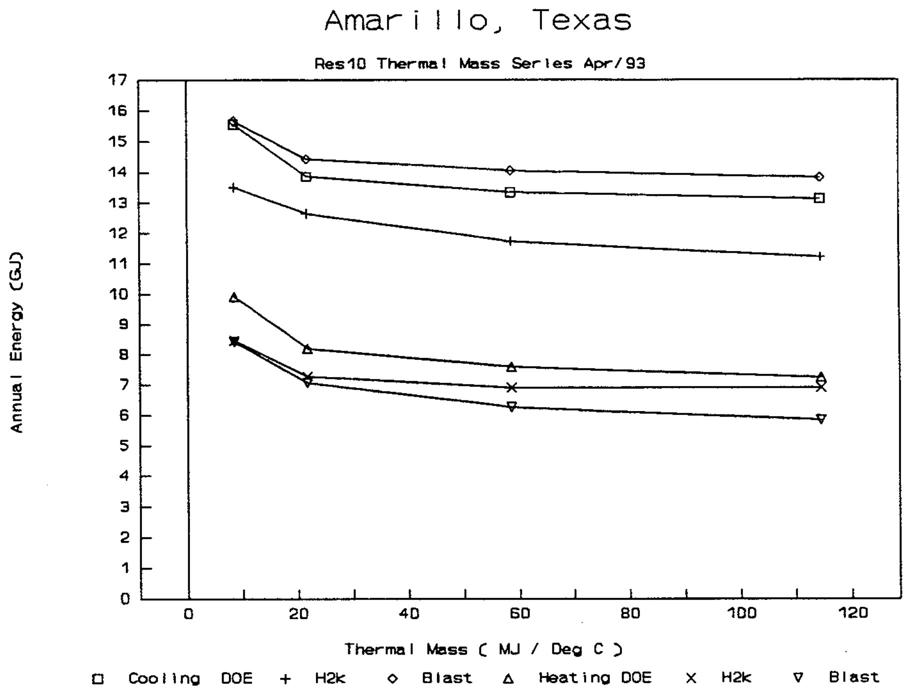


Figure 10c. Series Res10 Ventilation Rate



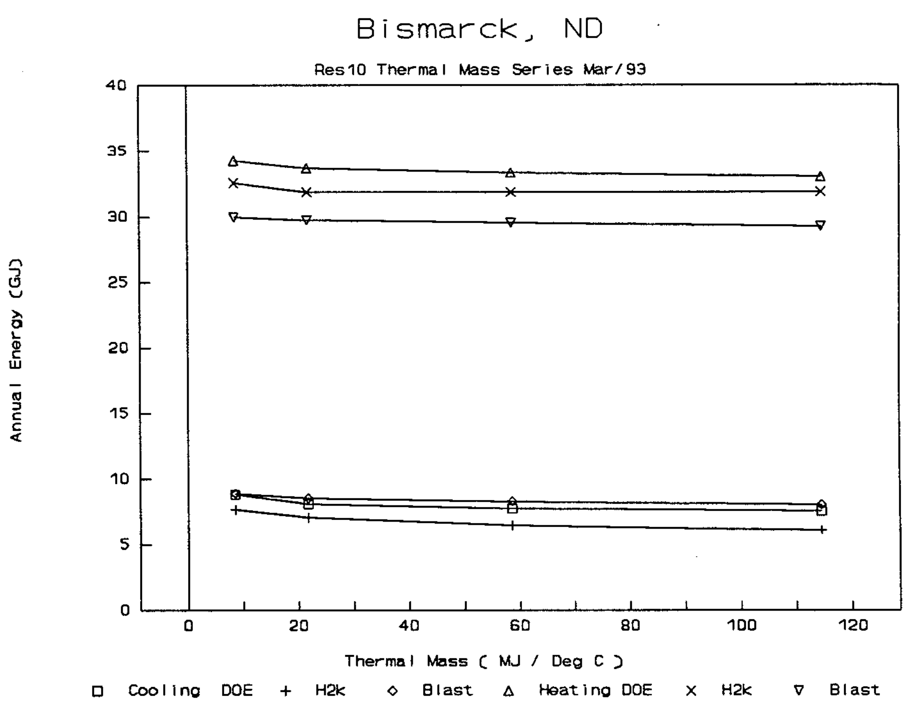
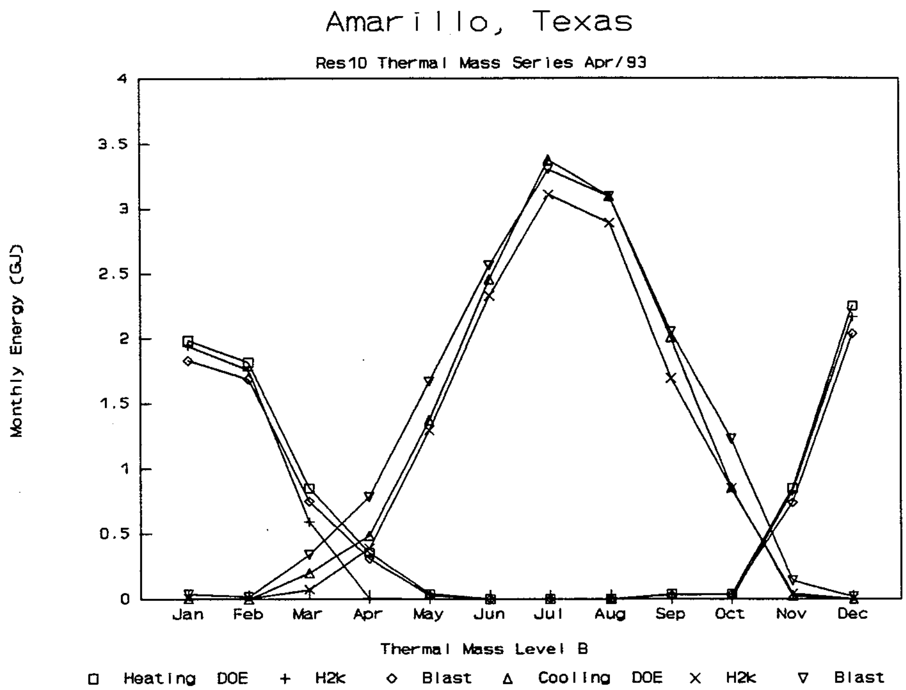


Figure 11a. Series Res10 Thermal Mass



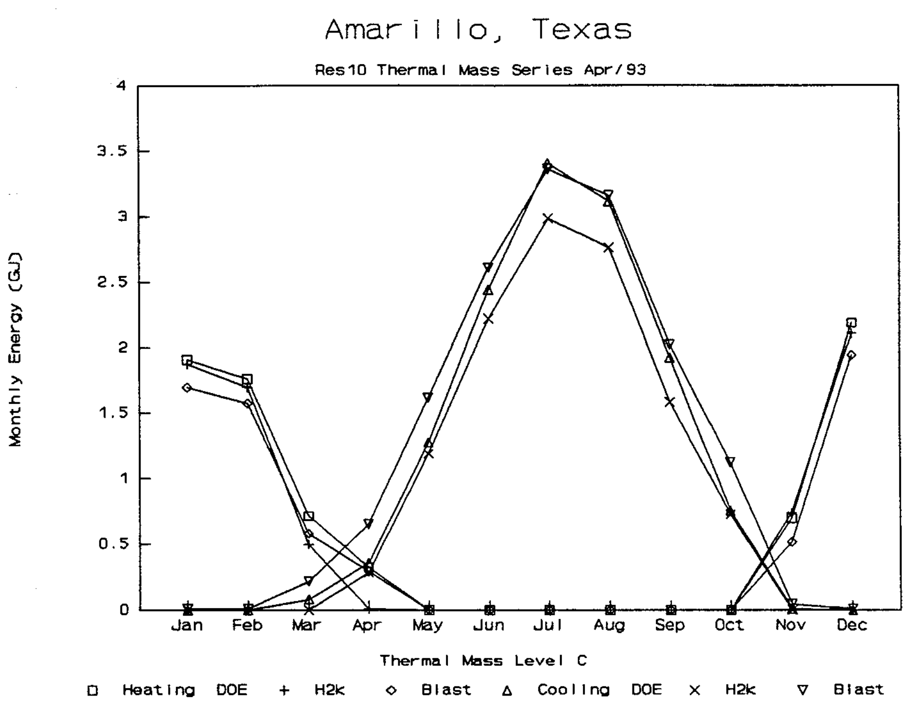
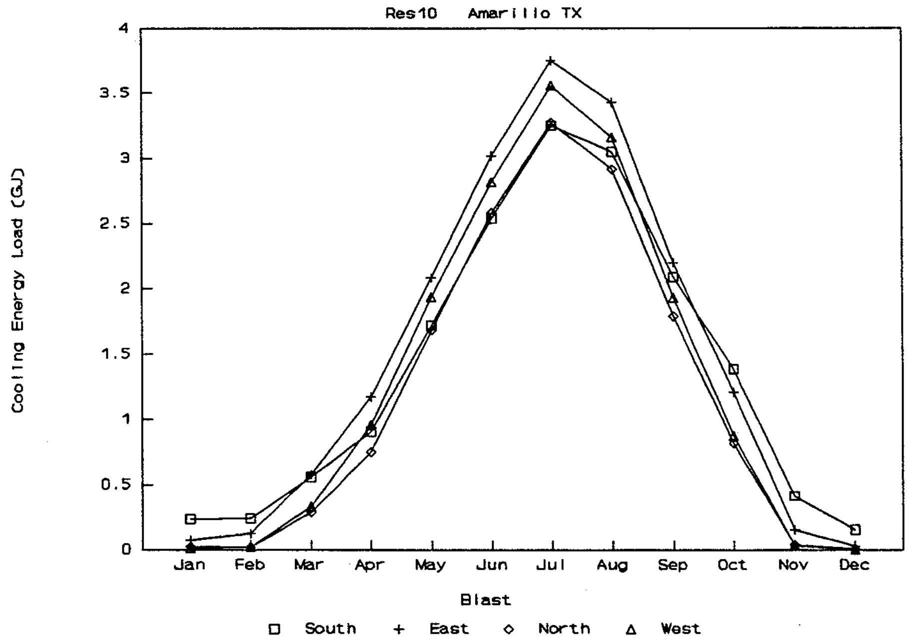


Figure 11b. Series Res10 Thermal Mass



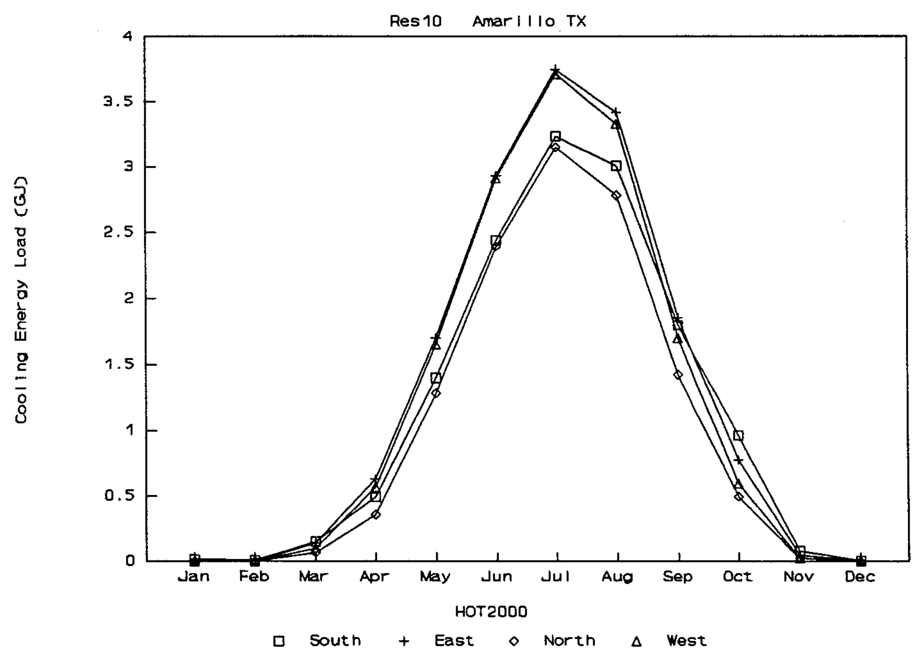


Figure 12. Res10 House Orientation Series

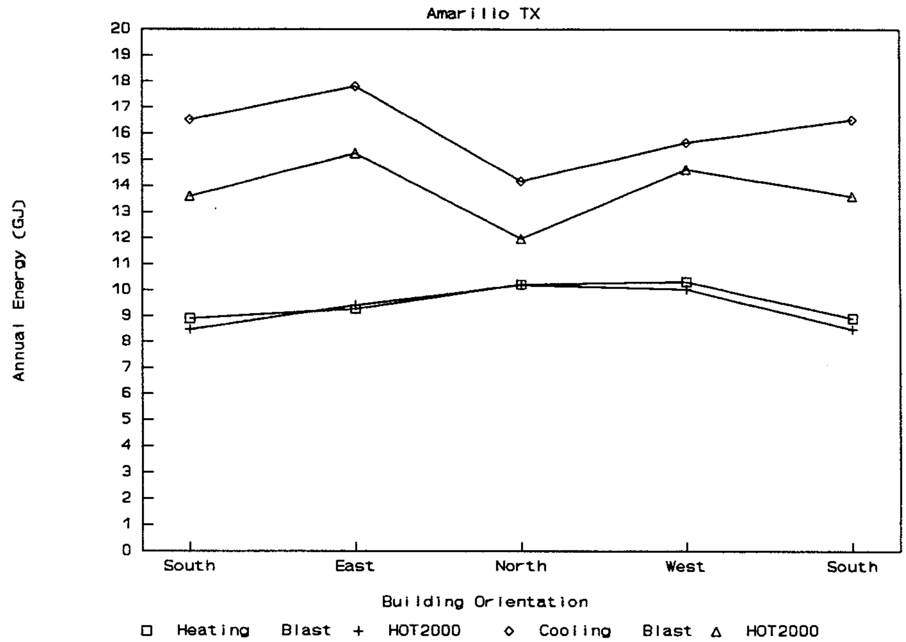


Figure 13. Res10 - Sensitivity to Orientation