

THERMAL CHARACTERISTICS AND SYSTEMS OF  
RESIDENTIAL CONSTRUCTION IN COLLEGE STATION, TEXAS: 1981-1986

David E. Claridge  
Paul Neidinger  
Derek Schrock

## I. INTRODUCTION

This paper examines the energy efficiency of residential construction in College Station from 1981-1986. Housing sizes, location, and construction activity by various contractors are described using data summarized from the College Station building permit book for this period. Site visits were made to apartments in complexes with over 20 percent of the multi-family units built during 1981-1986 and to selected single-family houses built by contractors responsible for over 25 percent of the single-family construction during this period. The information obtained on these visits was used to define the thermal characteristics and systems of base cases representative of below-average and average multi-family units, and average and above average single-family units.

These base-case units are compared to the specifications of the 1986 Model Energy Code(1) to determine the extent of energy code compliance by residential construction during this period. The energy efficiency of the base cases was investigated using the CIRA computer program(2). Additional base cases were defined and simulated for multi-family units constructed to code minimum and to the "above-average" single-family standards. Single-family units based on code minimums and below-average multi-family practices were also defined and simulated. A cost-benefit analysis of the different cases defined is presented based on current College Station utility costs and construction cost estimates.

## II. RESIDENTIAL CONSTRUCTION IN COLLEGE STATION: 1981-1986

From 1981-1986, 6,415 units of housing were built in College Station with a value \$181.78 million, as shown in Table 1. Residential construction was booming at the beginning of this period, peaking at 2,377 units and \$64.57 million in 1982. However, it dropped to less than half this level in 1983 and 1984 and decreased even further to 119 units and \$7.5 million in 1986.

Based on projected population growth in Brazos county to the year 2000, the average

rate of residential construction in College Station for the next 13 years should be 600 to 800 housing units annually. This is well below the boom years of 1981-82, but similar to 1983-84 when residential construction approximated \$25 million per year.

### Single-Family Construction

The nearly 2000 permits for new residential construction granted from 1981-86 have been analyzed for several salient features. The local building industry is highly fragmented; Figure 1 shows the number of houses built by 44 contractors who built 1014 or 73 percent of the 1389 single family houses granted building permits during this period. Over 200 permit holders are shown in the permit book; of course, many are individuals who do not build houses on a regular basis. The figure slightly overstates the fragmentation in the industry since it does not account for changes in business partnerships and other entities where the same builders have built under multiple business names during this period. However, it appears that no contractor built over 8 percent of these homes, and the largest contractor still building in the College Station market has built only 5 percent of the single family houses built during this period.

The houses have been built in 38 different subdivisions. However, there is substantial concentration in six subdivisions which account for nearly two-thirds of the houses built.

The size distribution of houses built is shown in Figure 2. Several groupings can be noted with slightly over one-third of the houses smaller than 1400 SF, another 40 percent were between 1400 and 2000 SF, about 15 percent were between 2000 and 2500 SF, and only 10 percent of the houses built were larger than 2500 SF. The median house (half smaller, half larger) built during 1981-1986 was about 1550 SF and the average size was about 1700 SF. This is comparable to the median of 1500 SF (average of 1660 SF) during the peak year 1982, but is much smaller than the median of 1800 SF (average

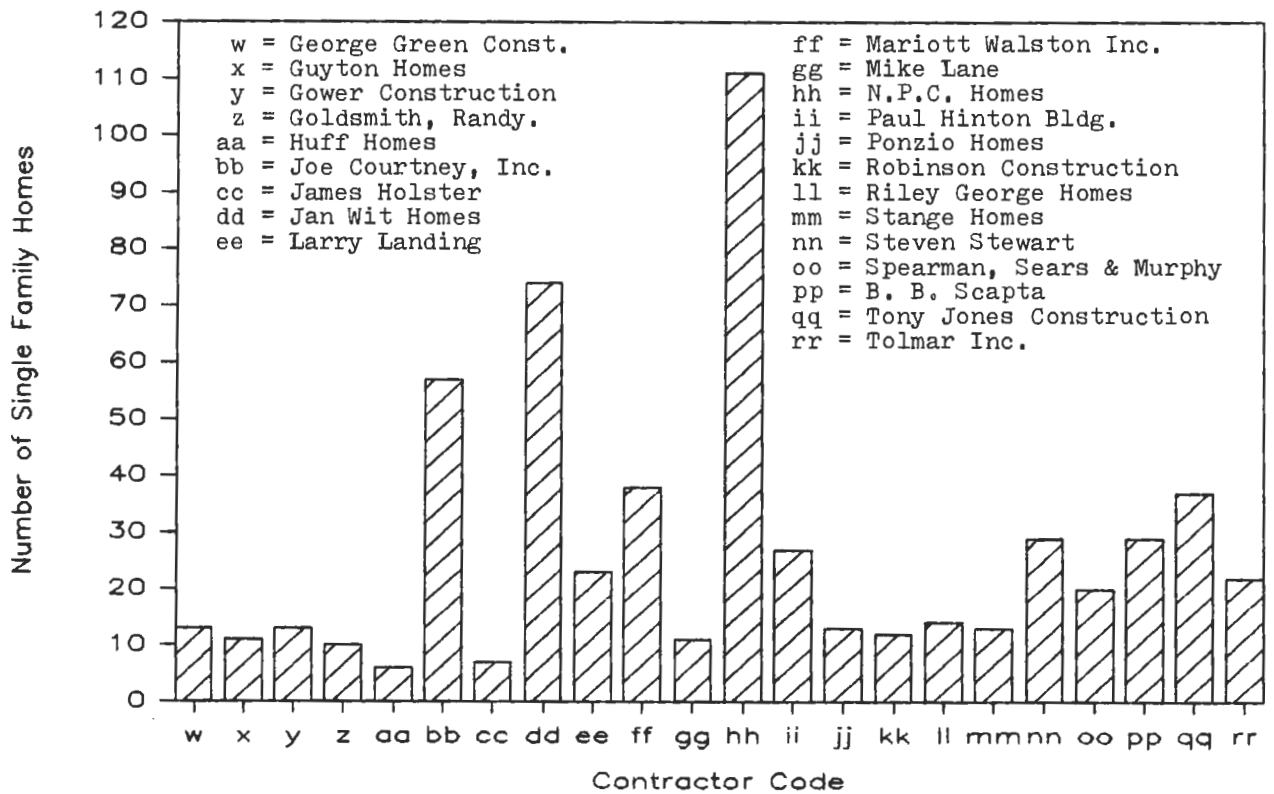
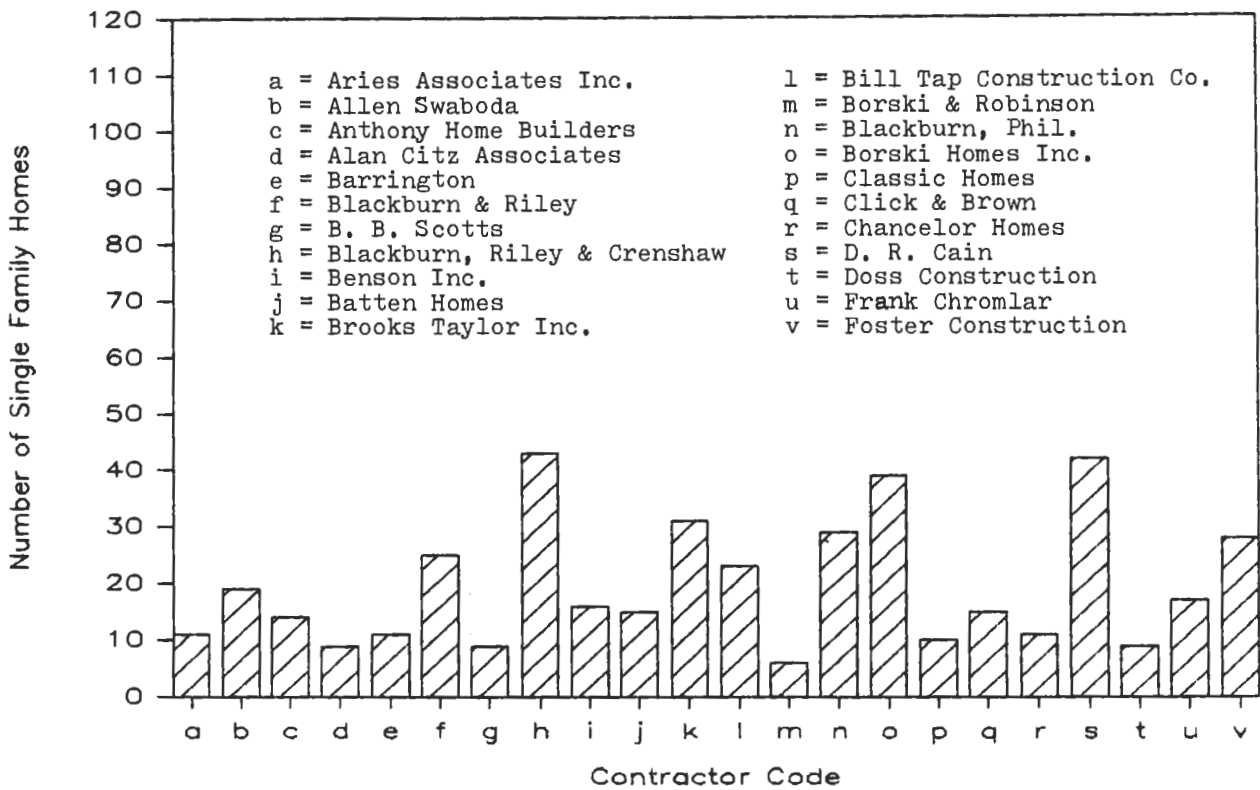


Figure 1. Number of single family homes built by individual contractors in College Station, 1981-1986.

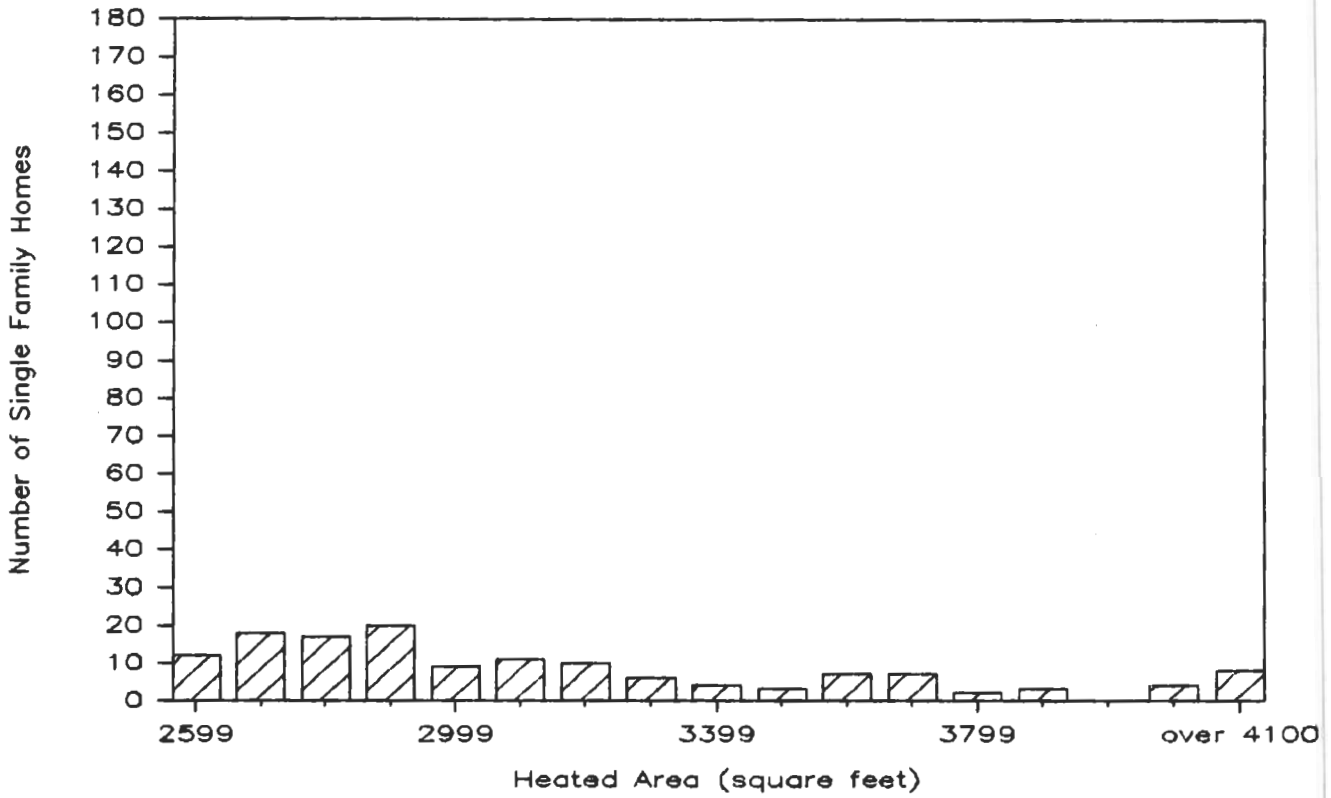
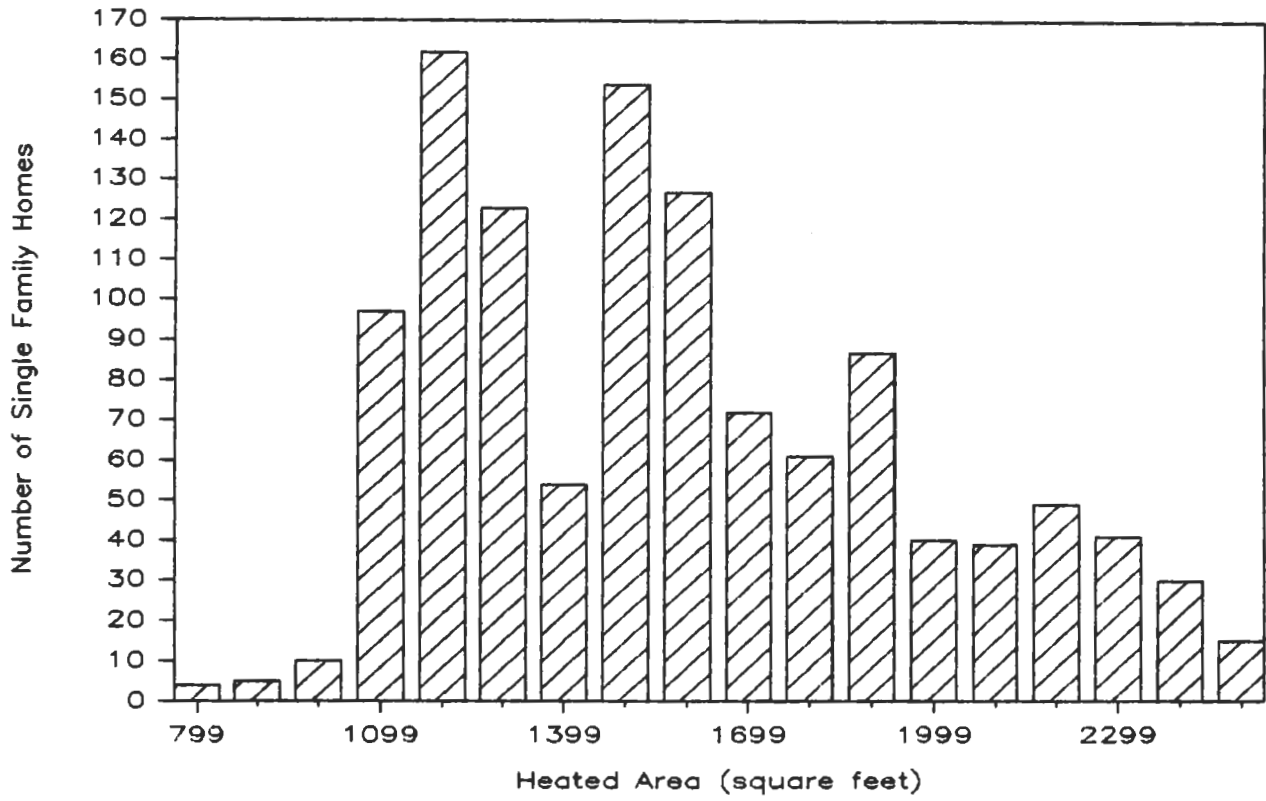


Figure 2. Distribution of single family homes built in College Station, 1981-1986, by heated floor area.

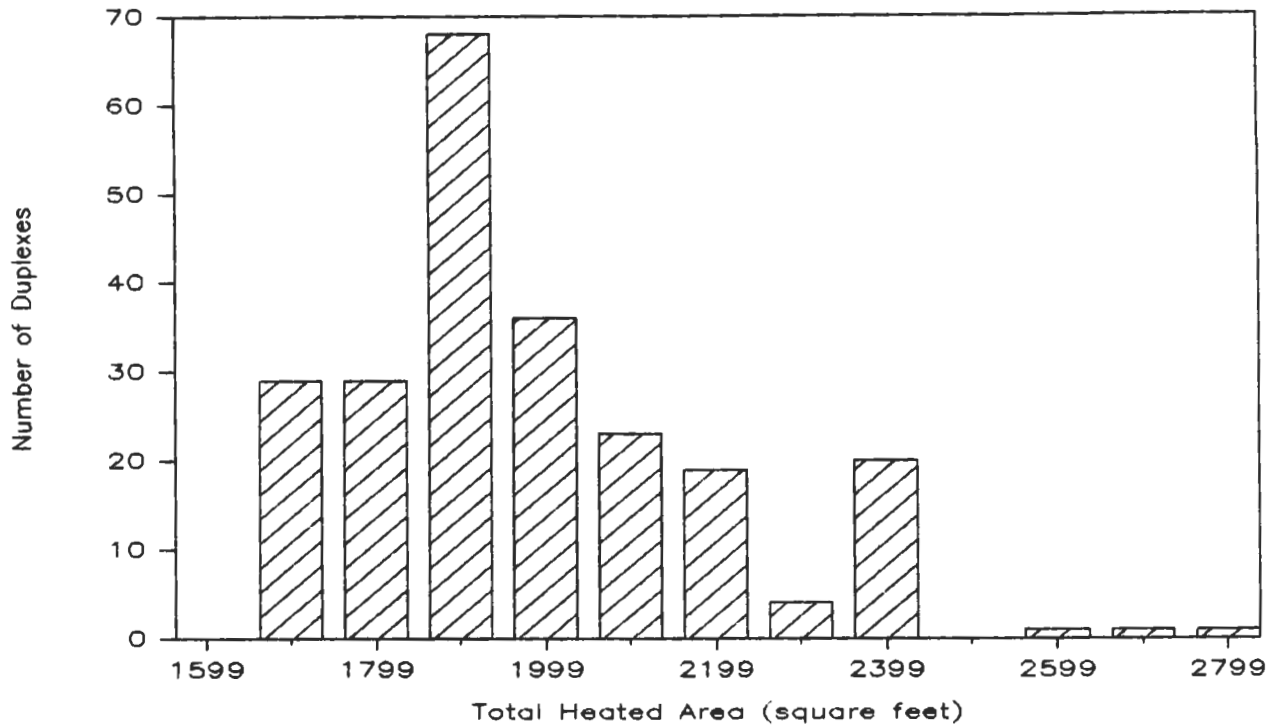


Figure 3. Distribution of duplexes built in College Station, 1981-1986 by heated floor area.

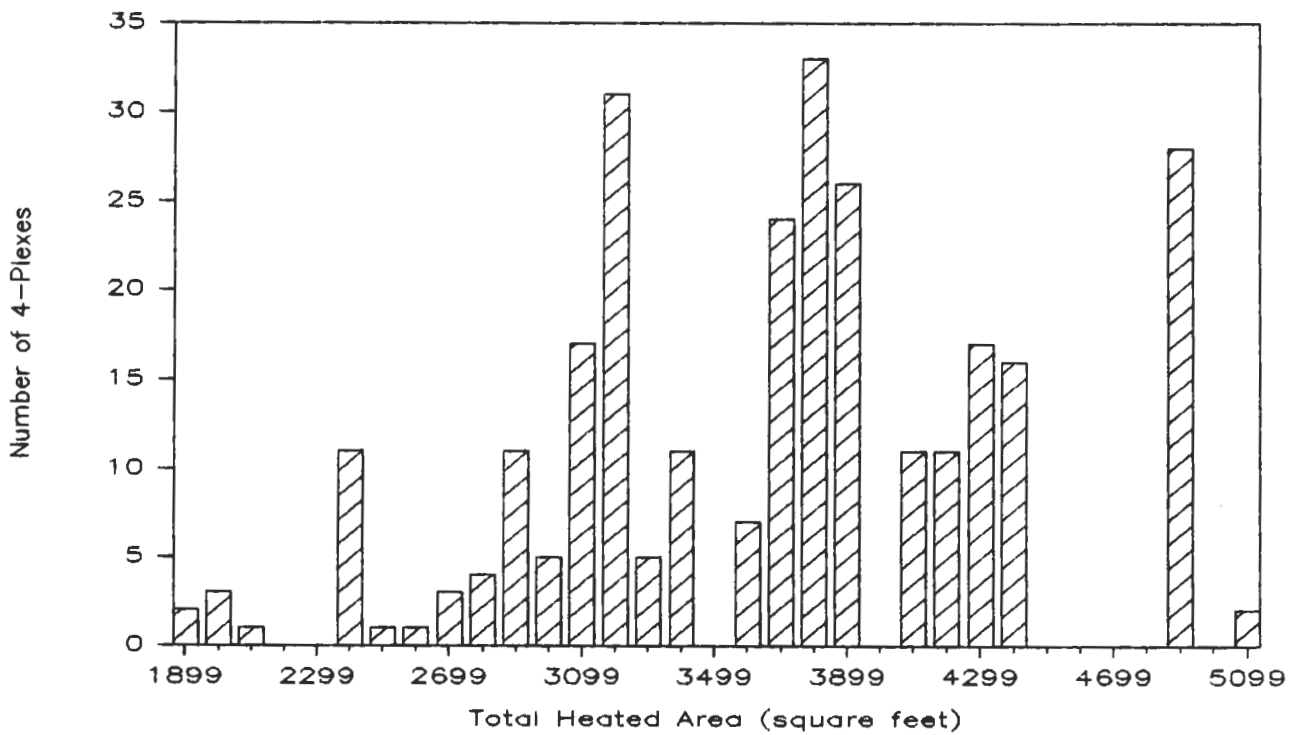


Figure 4. Distribution of four-plexes built in College Station, 1981-1986, by heated floor area.

Table 1  
Summary of Residential Construction in College Station:  
1981-1986.

Year	Single Family Houses	Duplexes	Apartments (# units)	Value (millions \$)	
1981	295	112	196	1463	50.67
1982	443	127	93	1680	64.57
1983	376	33	15	328	27.28
1984	116	1	17	835	23.50
1985	68	0	2	146	8.26
1986	91	0	1	28	7.5
Total	1389	273	324	4480	181.78

of 1970 SF) during 1986. This size trend is normal during industry slow-downs; the spec home market for smaller homes tends to contract more sharply than the market for larger homes. It is also probable that the drop in interest rates during 1986 has accentuated this trend.

#### Multi-Family Construction

The multi-family construction is divided among duplexes, fourplexes, and other multi-family buildings. The locations and size of the duplexes are summarized in Figure 3. Two-hundred seventy-three duplexes were built (546 units), and with the exception of six units, all had 800-1200 SF per unit. They were heavily concentrated in two subdivisions. About two-thirds were built in Southwood Valley and West Ridge, with the remaining third scattered among eight other subdivisions. Thirty-two contractors built one or more duplexes, but there was appreciably more market concentration than in single-family construction. The largest contractor built almost 20 percent of the total, and the four largest built about 40 percent of the total.

The four-plex market, as shown in Figure 4, shares many similarities with the duplexes. The units range from 500-1200+ SF in size, with most clustered around 800 SF or 1000 SF. They are heavily concentrated, with nearly two-thirds of the units in two subdivisions. The others are scattered in nine other subdivisions. Thirty one contractors built four-plexes, the largest building nearly 20 percent, and the four largest about 35 percent.

The remaining multi-family units are located in about 30 complexes which average approximately 100 units per complex. Many of these complexes are clusters of four-plex buildings.

### III. BASE CASE BUILDINGS

The thermal characteristics of residential construction have been surveyed to define typical base case buildings or units. The results of this survey are presented in this section. Based on our examination of construction practices, multi-family units generally have a combination of thermal characteristics and systems which require substantially higher energy cost per square foot than the single family houses built during this period. Consequently, four base cases have been defined: (1) a best case typifying the best single-family construction practice found; (2) a case "typical" of single-family house construction practice; (3) a case "typical" of multi-family construction practice; and (4) a case typifying below-average multi-family construction practice.

The base cases have been determined based on site visits to a large number of apartments and houses. These preliminary base case characteristics were then verified based on interviews with local builders and the College Station Energy Department.

#### Multi-Family Base Cases

During 1981-1986, a total of 4,753 multi-family housing units were granted building permits in College Station. Visits were made to complexes containing over 1000 of these units. Based on the information observed, the two multi-family base cases are defined as shown below:

##### Typical Multi-Family Unit:

- 2 bedroom unit in a 4-plex
- 900 SF
- R-11 wall construction
- R-19 ceiling construction
- 100 SF of single glazed sliders
- dark roof color
- infiltration approximately 0.9 ACH
- attic vents: soffit vents with turbine ventilators
- shading: minimal
- heating system: electric resistance
- air conditioner: 6.76 SEER
- electric hot water

##### Below Average Multi-Family Unit:

- 2 bedroom unit in 4-plex
- 900 SF
- R-11 wall construction
- R-11 attic insulation
- 110 SF single glazed sliders
- dark color roof
- infiltration approximately 1 ACH

- no attic vents
- minimal shading
- electric resistance heating
- air conditioner: 6.2 SEER
- electric hot water

- soffit & ridge vents (and/or turbines)
- shading by trees and overhangs
- gas heating with AFUE = 0.7
- gas hot water
- air conditioner with SEER = 10.0

It should be noted that the only item changed on the basis of builder interviews was the attic venting. Gable-end louvers were originally used in the base cases. The infiltration values are estimates and are not based on leakage area measurements.

#### Single-Family House Base Cases

The 1389 single family houses noted in Table 1 were constructed under 1389 different permits. Furthermore, since the larger contractors only build about 10 houses per year in College Station, it isn't possible to find plans which have been replicated 50-100 times or more as would be the case in larger metropolitan areas. Consequently, the houses visited were chosen differently from the multi-family visits. Houses were initially chosen to represent the early and late years of the period 1981-1986. It was expected that appreciable changes would be observed, i.e. that 1986 houses would be built to higher thermal/system standards than 1981 houses. However, the changes observed were small. There has been minor improvement in the air conditioner efficiencies, and builders interviewed indicated some improvements, such as increased use of double glazing and increased care in items affecting air leakage, but the changes have been relatively small.

The single-family house base cases as based on the site visits are given below:

Typical single-family house:

- 1600 SF slab-on-grade construction
- R-11 wall construction
- R-19 attic insulation
- 136 SF single glazed sliders
- dark roof color
- infiltration of approximately 0.7 ACH
- soffit vents and turbines
- minimal shading
- gas heating with AFUE = 0.7
- air conditioner with SEER = 7.95
- gas hot water.

Best Case House:

- R-18 wall construction (R-13 + foam sheathing)
- R-30 attic construction
- 136 SF double glazed sliders
- dark roof color
- infiltration of approximately 0.5 ACH

The interviews revealed an interest in the merits of slab insulation on the part of some builders and a complete lack of awareness of the different AFUE ratings available for gas furnaces.

The 17 homes visited were built by eight contractors who have built 27 percent of the single-family homes built during 1981-1986. Since the builder interviews indicated scarcely any thermal variation among the different units built by the same contractor, it is reasonable to assume the units visited are representative of at least 27 percent of the homes built during 1981-1986.

#### IV. COMPARISON WITH MODEL ENERGY CODE

The base cases have been compared with the 1986 Model Energy Code(1) (MEC) to determine the extent to which current construction meets this code. The best cases were clearly expected to pass the code. However, it was initially expected that some of the units with poorer thermal characteristics and systems would not pass the current code.

Comparisons were made in the following areas:

Attic insulation: Code requires a minimum of R-19 insulation. All units inspected except one large multi-family complex with approximately R-11 attic insulation met this requirement. However, wall insulation above code minimums can be used to offset this deficiency, and was in the complex noted above.

Wall insulation/windows: The code requirements are related to the overall heat-loss characteristics of the walls and windows. For the normal window areas observed, this corresponds to approximately R-3 insulation in normal frame-wall construction in apartment buildings and to approximately R-4 in the typical single-family house. The visits and builder interviews indicate that all construction has used at least R-11 insulation in the walls. These observations are also consistent with thermograms made of homes in College Station. Most units used single-glazing, but several builders now routinely use double glazing.

Infiltration characteristics: It was not possible to determine the extent of compliance with this portion of the code

from the site visits. The builder interviews indicate considerable attention to air leakage construction details by the builders interviewed, but these builders were generally building to thermal standards above the average of the houses inspected. The thermograms have indicated serious air leakage problems in many units.

Heating/Cooling equipment: All but one of the houses examined had air conditioners which met or exceeded the 1986 MEC. The apartments did not meet these requirements, but some did meet the 1983 MEC(3) requirements in this area (6.8 SEER) and all met the 1977 MEC(4) in effect when most of these units were built. None of the builders interviewed were aware of the different Annual Fuel Utilization Efficiency (AFUE) ratings available in gas furnaces, but virtually all equipment sold meets the MEC requirements for AFUE.

In summary, all of the single-family houses examined somewhat exceeded the code minimums (noting that this survey did not address air leakage standards). None of the multi-family units examined met the current code minimums for air conditioner SEER, but they did meet the standard in effect at time of construction. When the overall characteristics of the ceilings and walls were considered, even the poorest multi-family units examined passed the envelope standard.

#### V. COST/BENEFIT ANALYSIS OF DIFFERENT BASE CASES

This analysis examines the multi-family units and the single-family houses in separate analyses.

##### Multi-Family Cost/Benefit Analysis

This analysis examines the two base cases described above, the "Below Average" and the "Typical" multi-family unit. For purposes of this comparison, two additional cases are also considered: a unit constructed to the current MEC minimum standard and a unit constructed like the "Best Case" single-family house. (Note that these units are hypothetical - they do not represent units actually observed). Table 2 compares the predicted energy use of each unit and the annual energy cost, based on electricity which costs \$0.088/kWh and gas at \$0.50/therm. It can be seen that the energy cost of the best case is about half that of the other units. This has been accomplished by the following measures:

1. Switch from electric heating and hot water to gas.
2. Use R-30 attic insulation

3. Tighten air leakage to approximately 0.5 air changes per hour.
4. Use SEER = 10 air conditioner
5. Use R-13 wall insulation and one-inch foam sheathing.

The cost of these measures is estimated to be \$1200 - \$1600 for a 900 SF apartment unit, with annual energy savings of \$718 relative to the 1986 MEC minimum standard. The average payback is approximately 2 years. The additional cost on a 30 year mortgage at 10 percent for these improvements is \$10.50 - \$14.00/month while the savings are \$59.80. Savings like these should translate to increased occupancy rates, rental rates or both if the savings are credible to tenants. This could provide a clear benefit to owners and tenants.

Table 2

Comparison of Energy Use and Cost for Different Multi-Family Base Cases.

Base Case	Electric Use (kWh)	Electric Cost (\$)	Gas Use (MMBtu)	Gas Cost (\$)	Total Cost (\$)
Below Average	17583	1547	-	-	1547
1986 MEC	16538	1455	-	-	1455
Typical Unit	16074	1414	-	-	1414
Best Case	6891	606	30.3	151	737

The current electric bills for typical 2 bedroom units in College Station generally range from \$1200 - \$1500 per year. For rentals in the \$300 - \$400/month range, this means that electricity costs 25 - 40 percent as much as rent. This is a major expense, and as shown above, this is true for buildings which meet or exceed the 1986 Model Energy Code.

##### Cost/Benefit Analysis for Single-Family Houses

The simulations results for the single-family base cases are shown in Table 3 below. Results are shown for the typical single-family house and the "best" house described earlier. However, results are also shown for a case built using the typical thermal characteristics and systems of the "Below-Average" apartment and two different cases built to the minimums of the 1986 Model Energy Code. One case uses gas heat and hot water and the other uses electric resistance heat and hot water. Note that these minimum code cases are based on meeting the minimum envelope standards and equipment efficiencies as outlined in Section 6 of the Code. It is probable that higher energy bills would

result if a minimum code house was constructed using Section 4 of the Code.

Several observations can be made about the results shown in this table. The typical house built in College Station saves about \$175 per year relative to the minimum code house using gas heat and hot water. However, if gas was not available, and a house were built to minimum code, it would be extremely expensive to operate. This suggests the need for a tighter code for houses with electric heat and hot water.

Table 3

Comparison of Energy Use and Cost for Different Single-Family House Base Cases.

Base Case	Electric Use (KWh)	Electric Cost (\$)	Gas Use (MMBtu)	Gas Cost (\$)	Total Cost (\$)
"Below Avg Apt."	32080	2823	-	-	2823
1986 MEC Elec.	31380	2761	-	-	2761
1986 MEC Gas	13263	1167	86.3	432	1599
Typical House	12255	1078	69.3	347	1425
"Best" (SG)	10356	911	55.6	278	1189
"Best" (DG)	10258	903	51.9	260	1163

The best house with single glazing would cost \$1800-\$2600 more than the typical house. It produces monthly savings of \$23 and would reduce the monthly mortgage payments at 10 percent interest by \$14-\$20. This difference is not as dramatic as for the multi-family units, but would still be in the interest of the buyer - especially if an agreement were negotiated with lenders to allow consideration of energy cost in the qualification formula.

The "best" house with double glazing is a good example of an item which suggests the need for a rating system to help builders market energy efficiency. The double glazing provides benefits such as greater comfort and sound isolation in addition to the lower energy bills. The energy savings alone would not pay for the increased mortgage costs, but several builders are using double glazing because of the combination of benefits it provides. A rating system would help in this marketing effort.

#### Demand Reduction

The cost/benefit analysis above has addressed only the reduced energy use possible with energy efficient construction. Major demand reduction is also possible. If the 10,000 residential units expected to be built in College Station by the year 2000 were to use SEER = 10 air conditioners instead of the code

minimum SEER = 7.8, this would result in peak coincident demand reduction of approximately 8 MW (based on a 2.5 ton air conditioner averaged for multi-family and single-family construction).

Energy efficient construction will also make equipment down-sizing possible. An average half-ton reduction in air conditioner size would result in an additional 6 MW reduction in demand, for a total potential reduction in peak demand of 14 MW.

This may understate the potential. The Good Cents program measured an average reduction in monthly peak coincident demand of 1.6 kW compared to standard construction in 6 areas. The summer coincident demand was reduced by over 2.5 kW, compared with the 1.4 kW reduction assumed above.

#### Other Energy Efficiency Measures

The "Best Case" house and multi-family unit used in the cost-benefit comparison did not address all of the energy efficiency measures which can be considered in an energy code. They only incorporated measures which have been used in a significant number of single-family homes built in College Station.

#### VI. CONCLUSIONS

This study of construction in College Station for 1981-1986 leads to the following conclusions:

1. Builders are meeting the code in effect at the time of construction.
2. The 1986 Model Energy Code allows construction of multi-family units where energy cost is 25 - 40 percent of monthly rent. This is a major code deficiency.
3. The current cost differences between electricity and gas appear to warrant different standards for electrically heated buildings and hot water.
4. Major future reduction in demand growth (possibly 14 MW by the year 2000) is possible with an upgraded code.
5. Homeowners, tenants and apartment owners could all experience lower housing costs as a result of an upgraded code.
6. Numerous energy efficiency measures not explicitly considered in this study would result in further savings.



## REFERENCES

1. Model Energy Code 1986 Edition,  
Council of American Building Officials,  
5203 Leesburg Pike, Falls Church, VA 22041,  
1986.
2. CIRA 1.0 Reference Manual,  
Lawrence Berkeley Laboratory, Berkeley, CA  
94720, 1982.
3. Model Energy Code 1983 Edition,  
Council of American Building Officials,  
5203 Leesburg Pike, Falls Church, VA 22041,  
1983.
4. Model Energy Code 1977 Edition,  
Council of American Building Officials,  
5203 Leesburg Pike, Falls Church, VA 22041,  
1977.