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# Seven-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units

by  
Robert D. Neathammer

To determine if manufactured/factory-built family housing is more cost-effective in providing housing than conventional construction, Congress directed that a test be conducted of construction methods. In 1982, Congress authorized the construction of 200 units of manufactured/factory-built housing at Fort Irwin, CA, and concurrently, 144 units of conventionally built units.

Congress directed the Department of Defense (DOD) to conduct a fair and reliable study comparing the operation and maintenance (O&M) costs of manufactured housing to those of conventional housing. DOD reported to Congressional committees on the conditions and parameters under which this test would be conducted and the results of the test after the housing had been in use for 5 years.

The Assistant Secretary of the Army for Installations, Logistics and Environment requested that the study be extended beyond the 5 years. This report compares the first 7 years of O&M costs.

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## FOREWORD

This research was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC), under the following Intra Agency Orders (IAOs) from Fort Irwin and Headquarters, U.S. Army Forces Command (FORSCOM): FHAA022-83, dated August 1983; R039-84, dated May 1984; S040-85, dated January 1985; T016-86, dated November 1986; CERL-87, dated December 1987; CERL-88, dated June 1988; CERL-89, dated 2 March 1989; Headquarters, U.S. Army Corps of Engineers (HQUSACE) FAD 90-080031, dated September 1990; and (HQUSACOE) FAD 91-080025, dated September 1991. The USAEHSC technical monitor was Mr. Alex Houtzager (CEHSC-HM-O). Other technical advisors from USAEHSC were Mr. Robert Lubbert and Mr. Joe Hovell. Coordination and advice from FORSCOM were provided by Mr. Bill Mann, FCEN-RDM. The Fort Irwin advisor was Mr. Tom Cragg.

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**SEVEN-YEAR SUMMARY OF FORT IRWIN, CA, FAMILY HOUSING COMPARISON TEST: OPERATION AND MAINTENANCE COSTS OF MANUFACTURED vs. CONVENTIONALLY BUILT UNITS**

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**1 INTRODUCTION**

**Background**

Congress believes that use of manufactured (factory built) military housing, rather than conventionally built units, will result in lower overall costs and provide durable housing meeting contemporary housing standards. To verify this belief, Congress directed the Department of Defense (DOD) to construct 200 units of manufactured housing at Fort Irwin, CA, and compare them with similarly designed, conventionally built housing.<sup>1</sup> DOD was also directed to perform a study comparing the operation and maintenance (O&M) costs of the two types of construction over a 5-year period.

Results of the 5-year study showed no difference in O&M costs between the two types of construction. However, the Assistant Secretary of Army for Installations, Logistics, and Environment, the U.S. Army Engineering and Housing Support Center (USAEHSC), and the U.S. Army Construction Engineering Research Laboratory (USACERL) all think 5 years is too short a time for valid comparisons of these types of costs. Thus, USACERL was requested to continue collecting and analyzing data and report results at the end of each year in order to identify broad trends.

The manufactured units met Federal Manufactured Housing Construction and Safety Standards (FMHCSS); however, upgrades in certain criteria were specified to bring the units into conformance with DOD standards. These areas of concern included net usable floor space, energy efficiency, fire and life safety, and durability of certain materials and components. The study compared the impact of the modified FMHCSS versus standard DOD criteria, except for the essential criteria listed above.

The study began when the housing units were first occupied; initial occupancy of some units started in February 1983. The study compares 200 two-bedroom manufactured units to 144 two-bedroom, conventionally built units. The two types of units were similar in floor area, floor plans and materials used. The conditions and parameters for this test were submitted to Congress.

The data collected address O&M costs for both types of housing. The study identifies not only the differences, if any, in O&M costs, but also the reasons for the differences and their importance for future construction criteria, and construction methods.

**Objective**

This report summarizes the O&M costs for both conventionally built and manufactured housing from construction through the first 7 years of occupancy.

<sup>1</sup> Report No. 97-44, *Military Construction Authorization Act* (House of Representatives Committee on Armed Services, 1982), pp 8-9.

## Approach

The first step was to develop uniform data collection and data analysis procedures. The cost comparisons and analyses for this study were established in USACERL Special Report (SR) P-140.<sup>2</sup> Data were collected throughout the study and summarized/reported yearly. First year data were reported in USACERL Interim Report (IR) P-85/14,<sup>3</sup> second year data in USACERL IR P-86/06,<sup>4</sup> third year data in USACERL IR P-87/10,<sup>5</sup> fourth year data in USACERL IR P-88/09,<sup>6</sup> 4 1/2 year data in USACERL IP P-89/14,<sup>7</sup> fifth year data in USACERL TR P-90/11,<sup>8</sup> and sixth year data in USACERL TR P-91/37.<sup>9</sup>

Individuals were assigned to quarters with no distinction between the two types of units. The units all have the same floor area and were to be occupied by essentially the same ranks/ages of sponsors; i.e., the assignment of families was not biased by the type of construction.

## Scope

Costs were limited to buildings themselves, as the intent of the study was to compare O&M costs of the two types of construction. Thus, sidewalks, driveways, streets, lawns, playgrounds, and utility lines outside the buildings were not included. Also, the replacement costs of refrigerators, kitchen stoves, and utility meters were excluded. (Because of these exclusions, the unit cost data in this report is *not comparable* to standard unit cost data reported for family housing in many Army financial reports, which normally includes costs such as streets and utilities.)

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<sup>2</sup> M.J. O'Connor, *Fort Irwin Housing Comparison Test*, Special Report (SR) P-140/ADA130349 (USACERL, 1983).

<sup>3</sup> R.D. Neathammer, *Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, Interim Report (IR) P-85/14/ADA159740 (USACERL, 1985).

<sup>4</sup> R.D. Neathammer, *Two Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-86/06/ADA175995 (USACERL, 1986).

<sup>5</sup> R.D. Neathammer, *Three Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-87/10/ ADA180001 (USACERL, 1987).

<sup>6</sup> R.D. Neathammer, *Four-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-88/09/ADA190017 (USACERL, 1988).

<sup>7</sup> R.D. Neathammer, *May 1984 to September 1988 Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, IR P-89/14/ADA209421 (USACERL, 1989).

<sup>8</sup> R.D. Neathammer, *Five-Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operation and Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR P-90/11/ADA222176 (USACERL, 1990).

<sup>9</sup> R.D. Neathammer, *Six Year Summary of Fort Irwin, CA, Family Housing Comparison Test: Operational Maintenance Costs of Manufactured vs. Conventionally Built Units*, TR P 91/37/ADA237479 (USACERL, 1991).

## 2 REVIEW OF TEST PLAN

This section gives a short review of the test plan and the final data analyses. Data were collected for O&M costs.

USACERL SR P-140 detailed the cost data collection plan and analysis methods. Four basic questions on costs will be answered:

1. Were the average annual O&M costs significantly different?
2. If different, where were they significantly different?
3. Why did the costs differ?
4. What criteria, design features, etc., need to be changed as a result?

Overall maintenance costs and utility costs were compared separately. If significant differences were found, it is important to determine their causes.

In addition to the overall cost comparison, the maintenance costs for major building components were compared. These comparisons provide more detail about where and why cost differences occur.

Occupant satisfaction with the overall apartments and each physical part of the unit was compared for the two types of construction and reported in USACERL P-90/11. When occupant satisfaction differed for a building component, that component was evaluated to determine the reason for the difference.

### 3 DESCRIPTION OF THE FAMILY HOUSING UNITS

#### Manufactured Housing Units (MHUs)

These 200 units consist of 50 two-story fourplexes (two units on each of the first and second floors). Net floor area is 950 sq ft/unit.\* These were constructed on perimeter footing with wood floors and crawl spaces. Each upper unit has a balcony-porch and each lower one has a patio with privacy fencing. Figure 1 shows front and rear views of typical buildings. Each unit has a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace (all provided by the contractor). Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, utility room, and a one-car garage. The garage was constructed on site.

A detailed description of the construction process including photographs and floor plans for the units is shown in Appendix A.

The notice to proceed date was 10 January 1983. Initial occupancy was:

61 units	Dec 83
7 units	Jan 84
64 units	Feb 84
57 units	Apr 84
9 units	May 84
2 units	Jun 84

#### Conventionally Built Units (CBUs)

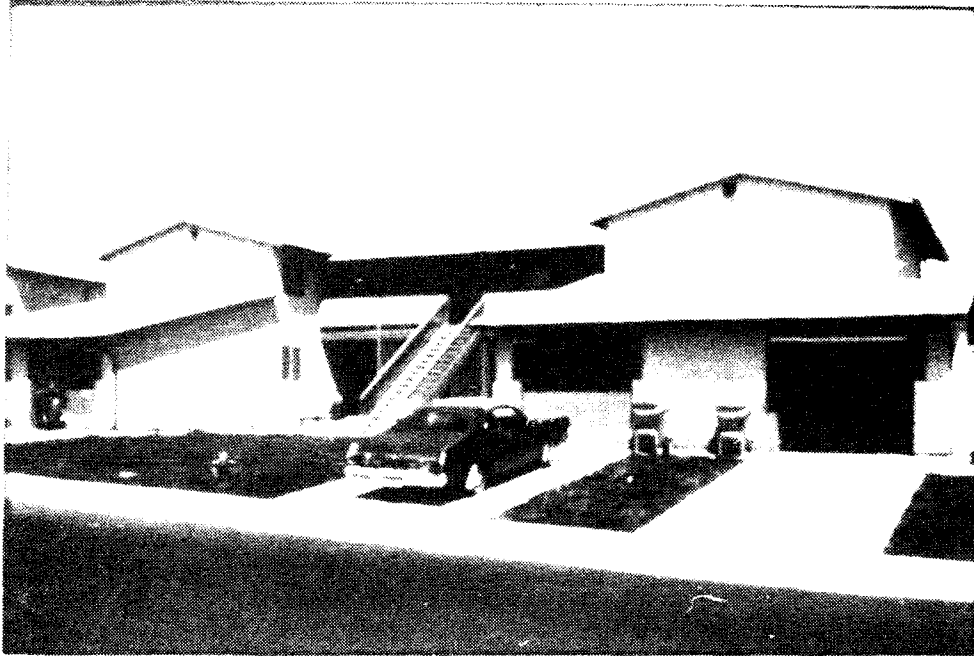
The 144 units consist of 13 sixplexes, 6 fiveplexes, and 9 fourplexes, all two-story buildings. Net floor area is 950 sq ft/unit. These units were constructed on perimeter footings with building slab. Each unit has two bedrooms, a kitchen, living-dining area, one bathroom, utility room, either a fenced patio or balcony-porch (for upper unit), and a one-car garage. Figure 2 shows front and rear views of typical buildings. The fourplexes have two units on each level. There are two units on the second story in the five- and sixplexes with the additional unit(s) on the first level. The CBUs also have a refrigerator, gas range, gas water heater, garbage disposal, dishwasher, central air conditioning, and gas-fired forced-air furnace.

The notice to proceed date was 3 May 1982. Initial occupancy was:

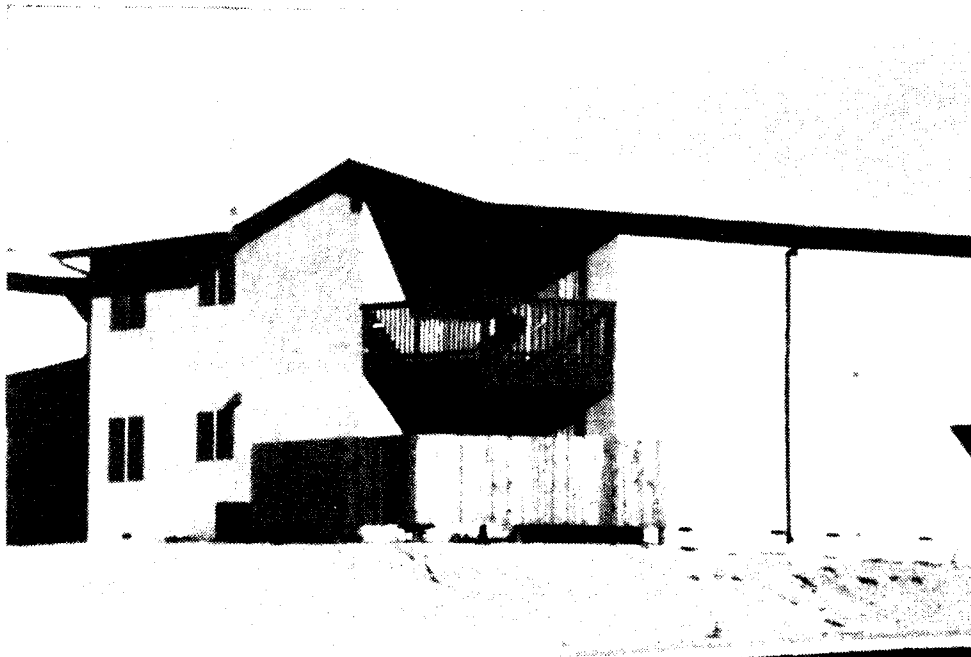
8 units	Feb 83
28 units	Mar 83
38 units	Apr 83
31 units	May 83
23 units	Jun 83
14 units	Jul 83
2 units	Aug 83

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\*Metric conversions: 1 cu ft = 0.028 m<sup>3</sup>; 1 sq ft = 0.093 m<sup>2</sup>; °C = 0.55 x (°F-32).

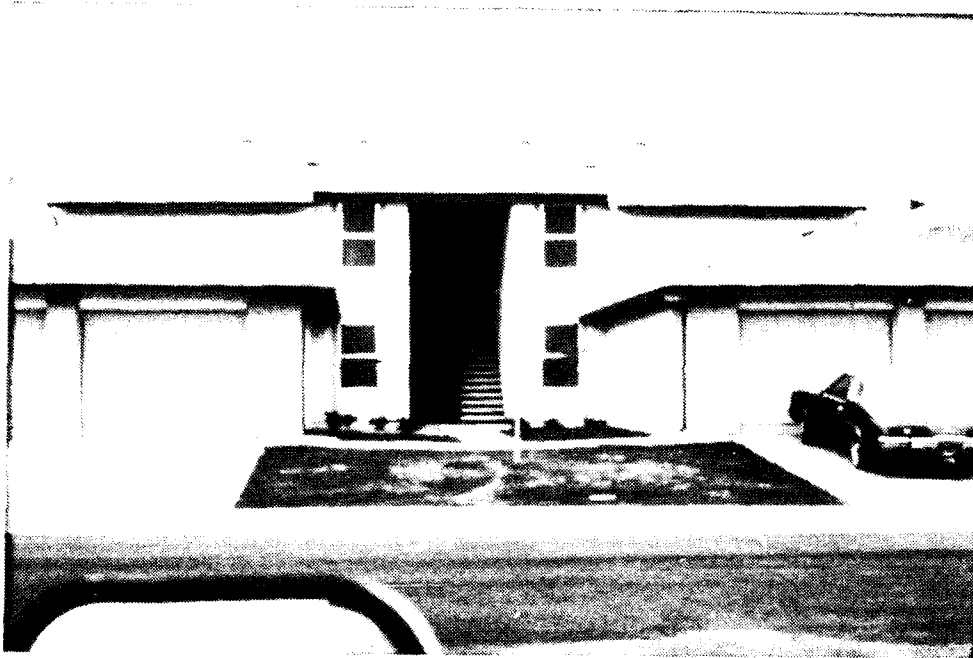


Front View - MHU



Rear View - MHU

Figure 1. Front and rear views of typical MHUs.



Front View - CBU



Rear View - CBU

Figure 2. Front and rear views of typical CBUs.

A detailed description of all units can be found in the Los Angeles District Office report.<sup>10</sup> The buildings were not specifically adapted to the desert environment but are typical Southern California design.

### Costs

A clear cut initial cost comparison was not possible. The 144 CBUs were part of a 254 unit project. The cost for this project was \$51.83/sq ft. The 200 MHUs costs were \$51.22/sq ft. However, the supervision and administration costs for the MHUs were based on the same 5 percent rate used for the CBUs. More actual labor was required since quality assurance inspection was required at the manufacturing plant as well as at the construction site. It was estimated that the additional labor would have raised the cost to \$55/sq ft (no records were kept as these are all indirect costs).

### General Comparison

Fort Irwin is located in a high desert environment. Annual rainfall averages 4 in. and temperatures often exceed 100 °F. The housing construction was not adapted to this climate but is representative of Southern California design.

The exterior finish of both types is basically stucco. Exterior trim is painted wood. There is some brick veneer on the garages. Asphalt shingles were used on both types, and gutters and downspouts were installed.

On the interiors, walls are painted gypsum board. Floors on the second level are carpeted and are vinyl tile or vinyl sheet covering on the first floor.

Water piping is copper in the CBUs and polybutylene in the MHUs.

Windows are single pane in the MHUs and are thermal pane in the CBUs.

Floors (first story) in MHUs are wood on crawl spaces and in CBUs are concrete slabs.

Grass was planted in the immediate yard area of the buildings, but not in play yard areas. Each first floor unit has a concrete patio, each second story unit a wooden balcony-porch. There is a wooden privacy fencing for each first floor unit.

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<sup>10</sup>*Fort Irwin Family Housing Study--A Report on Manufactured/Factory-Built Housing and Site-Built Housing, Fort Irwin, CA* (U.S. Army Corps of Engineers, Los Angeles District, September 1984).

## **4 DATA COLLECTION PROCEDURES**

Data were collected in enough detail that any differences found between the two types of construction could be explained. Appendix B lists the housing units and their identification numbers used in the data collection. Appendix C lists the building components and subcomponents. Each service order was coded to one of these so that costs of components could be compared. A discussion of the data collected is included in USACERL SR P-140.

### **Data Collection**

Discussions were held with representatives of the USAEHSC technical monitor, Forces Command Headquarters, Fort Irwin personnel, and the base operations contractor, Boeing Services International (BSI), to establish the best methods of collecting the data.

BSI was contracted to segregate all service orders for maintenance for the test units and report cost data to USACERL through the Fort Irwin Directorate of Engineering and Housing (DEH) on a monthly basis. BSI was also contracted to read gas and electric meters at the end of each month and report similarly.

A new contractor, Dynalectron, became the base operations contractor effective 1 October 1986 and performed the same services described above.

### **Data Verification**

USACERL verified the reported data several ways. For the first 5 years, each original work order (WO) document was checked against the reported data forwarded by the contractor. Discrepancies were resolved on verification visits to Fort Irwin. Additionally, the contractor set up separate accounting codes for the two groups of units and the total billed was compared to the total obtained from summing all the individual WO data. For years 6 and 7, the reported data was checked for obvious errors and these were resolved with the contractor. No detailed validation of each WO was made as the purpose of the continued study is to search for overall, large trends.

USACERL developed a computer program to compare gas and electricity meter readings. When apparently erroneous data occurred, the contractor was notified and corrections made.

### **Data Analysis**

#### *Maintenance Costs*

Maintenance costs were compared on a unit-month basis and yearly basis. The data were also summarized by building component to determine if one or more components for one of the types of units had large maintenance costs. If so, the reasons for these costs were determined; i.e., what criteria or design features should be reviewed/changed?

Cost differences could have been caused by material quality, installation, differences inherent to manufactured or conventional construction, and possible errors in specifications for the two projects.

Warranty work referred to the construction contractor was not included in the cost comparison since no cost data were available or applicable, as it was not a cost to the government. However, the cost of a service call to assess a problem was included.

### *Energy Consumption*

Gas and electricity consumption were compared on a quarterly basis and a yearly basis. Since most of the MHUs were not completed until May 1984, prior energy consumption data for the CBUs was not used in comparisons. (Energy consumption comparisons are only valid for the same time frame because of varying weather conditions.)

## 5 WHOLE HOUSE ENERGY TESTS

Energy evaluations of sample units of each type of construction were performed immediately after construction was completed on each of the two groups of housing and again after 5 years of occupancy. The objective was to determine if energy characteristics had changed over the 5-year period. Three whole-house energy tests were performed. Appendices D and E give details of the tests for the CBUs and MHUs, respectively.

### House Tightness

The number of air changes per hour were measured with the following results:

Type	<u>Immediately After Construction</u>			<u>After 5 Years</u>		
	<u>No. Units</u>	<u>Average Air Change Per Hour</u>	<u>Standard Deviation (%)</u>	<u>No. Units</u>	<u>Average Air Change Per Hour</u>	<u>Standard Deviation (%)</u>
CBU	15	13.0	1.06	15	12.1	1.70
MHU	12	10.9	2.67	14	9.7	1.60

There was a statistically significant difference between the two types of construction for both the initial and 5-year tests, the MHUs being more airtight on the average. Neither type of unit changed significantly over the 5 years. These results indicate that the MHUs should have had less air infiltration/leakage.

### Furnace Efficiency

The furnace efficiency results were as follows:

Type (%)	<u>Immediately After Construction</u>			<u>After 5 Years</u>		
	<u>No. Units</u>	<u>Average Efficiency (%)</u>	<u>Standard Deviation (%)</u>	<u>No. Units</u>	<u>Average Efficiency (%)</u>	<u>Standard Deviation</u>
CBU	13	66.2	6.24	14	64.2	12.2
MHU	16	79.3	3.36	15	77.3	2.84

The furnace efficiencies of the MHUs were significantly higher than those of the CBU for both the initial and 5-year tests. Neither type of unit changed significantly over the 5 years.

### Wall Heat Transfer Characteristics

This parameter was not initially measured for the CBUs because of unfavorable weather during the testing period. This parameter was calculated for both types of construction using the designed wall construction.

<u>Type</u>	<u>No. Units</u>	<u>Average Heat Loss (Btu/hr-°F)</u>
CBU	16	1072
MHU	15	1220

### Summary

The whole house energy tests did not conclusively indicate which type of unit would use less energy for heating/cooling. The CBUs are more energy efficient considering only the wall heat loss test, but the MHUs perform better when tested for air tightness and furnace efficiency. Additionally, the CBUs are built on concrete slabs while the MHUs have a crawl space. Concrete slabs are better (use less energy) than crawl spaces. This has an impact on the first floor units' energy use.

Thus the tests are inconclusive in predicting which type of construction would use more energy for heating/cooling.

## 6 OPERATION AND MAINTENANCE (O&M) COSTS

O&M costs for each type of unit were compared over the first 7 years of occupancy. For CBUs, this was 1 August 1983 through 31 July 1990 and for MHUs, 1 June 1984 through 31 May 1991.

### Overall Costs

The total housing unit-months and maintenance costs for the first 7 years of occupancy are shown in Table 1. (Maintenance includes all types of repairs and "preventive maintenance" performed.)

### Discussion

The MHUs cost about \$14/month more than the CBUs over the first 7 years of occupancy; the difference in cost per unit per year of an MHU is \$164. There were large increases in M&R costs in years 4 and 5. This is illustrated in Table 2, which shows M&R costs per year of occupancy.

**Table 1**

**Unit/Month Costs in First 7 Years' Occupancy**

Type	No. Unit Months	Total Cost (\$)	Cost/Unit/ Month (\$)	Cost/Unit/ Year (\$)
CBU	12,096	448,326	37.06	445
MHU	16,800	853,168	50.78	609

**Table 2**

**Yearly M&R Costs by Type of Construction**

Year	Total CBU (\$)	Cost/Unit (\$)	Total MHU (\$)	Cost/Unit (\$)
1	31,592	219	34,164	171
2	29,107	202	59,076	295
3	44,391	308	63,717	319
4	45,565	316	114,728	574
5	89,186	619	189,122	946
6	96,700	672	175,725	879
7	111,785	776	216,636	1083
7 Year Total	448,326	445	853,168	609

Costs per unit have been increasing over time. Figure 3 shows the cumulative cost per unit per month for ages 15 to 84 months, illustrating this trend. The costs for the MHUs increased slightly faster than for the CBUs. This can also be seen in Figure 4, which shows costs per unit per year.

Increased costs in years 4 and 5 were attributable partly to interior painting done in units vacated for the first time and in those which required painting on change of occupancy. Table 3 shows the painting costs per year of occupancy. Note the large increases for MHUs in year 5 and for CBUs in year 6. Painting costs for the MHUs may have stabilized in years 6 and 7.

Table 4 shows the yearly costs excluding interior painting. This table shows that the MHUs' costs increased slightly faster than did the CBUs' through year 5. Both showed decreases in year 6 and increases in year 7. Figure 5 displays this data.

### **Costs Excluding Certain Equipment Costs**

Since the purpose of this study was to compare maintenance costs attributable to method of construction, another table was generated excluding certain costs. Table 5 gives the costs for the 7 years of occupancy of each type unit, excluding any costs for maintenance of water heaters, garbage disposals, dishwashers, ranges, range hoods, and refrigerators (equipment not part of the construction process).

The difference in cost per unit per year between types of construction is \$122/year. Compared to the \$164 in Table 1, this is a better estimate of the cost difference attributable to the type of construction.

### **Costs Excluding Interior Painting and Equipment Costs**

In Table 6 equipment costs and painting costs are excluded. The difference for unit cost is \$85 per year. Figure 6 graphs the data of Table 6.

### **Number of Component Action and Work Orders**

Table 7 lists the number of component actions and work orders per year.

### **Maintenance Per Component**

Table 8 lists the frequencies of work orders and costs per building component for the two types of units. However, the costs were not directly comparable across the two types of units since there were 200 MHUs and 144 CBUs. Table 9 shows the cost data adjusted by multiplying the MHU costs by 0.72 (144/200). Also shown in Table 9 are the 7-year costs on a unit basis.

Table 9 shows that the total cost was less than \$500 for both types for 21 of the 78 components. For 42 of the other 57 components, the MHUs had a higher cost.

Most of the costs shown in Tables 8 and 9 were for building components independent of type of construction. For example, over \$15K was spent on the ranges for each type unit, \$16K for CBUs and \$60K for MHUs was spent on dishwashers, over \$20K on light fixtures for each type, etc. The most significant costs for components which differ for the types were roofing surface, exterior doors, garage doors, A/C refrigerant, bathroom/kitchen fixtures, and piping. Although a large difference existed for painting, this cost depended on rotation of occupants and occupant wear and tear. Complete quarters painting was done on 223 MHUs and only 114 CBUs.

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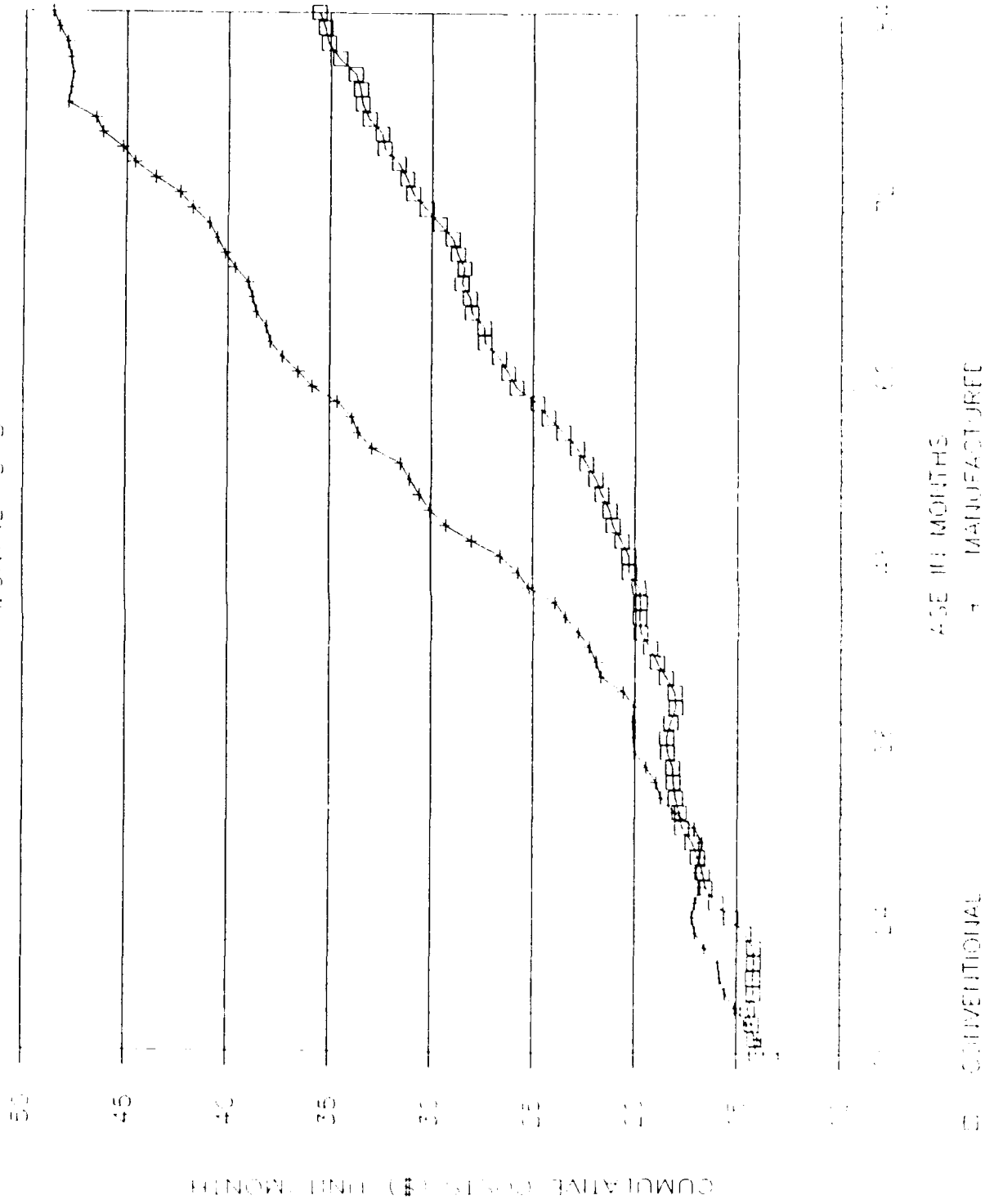


Figure 3. Cumulative cost per unit per month for ages 15 through 84 months.

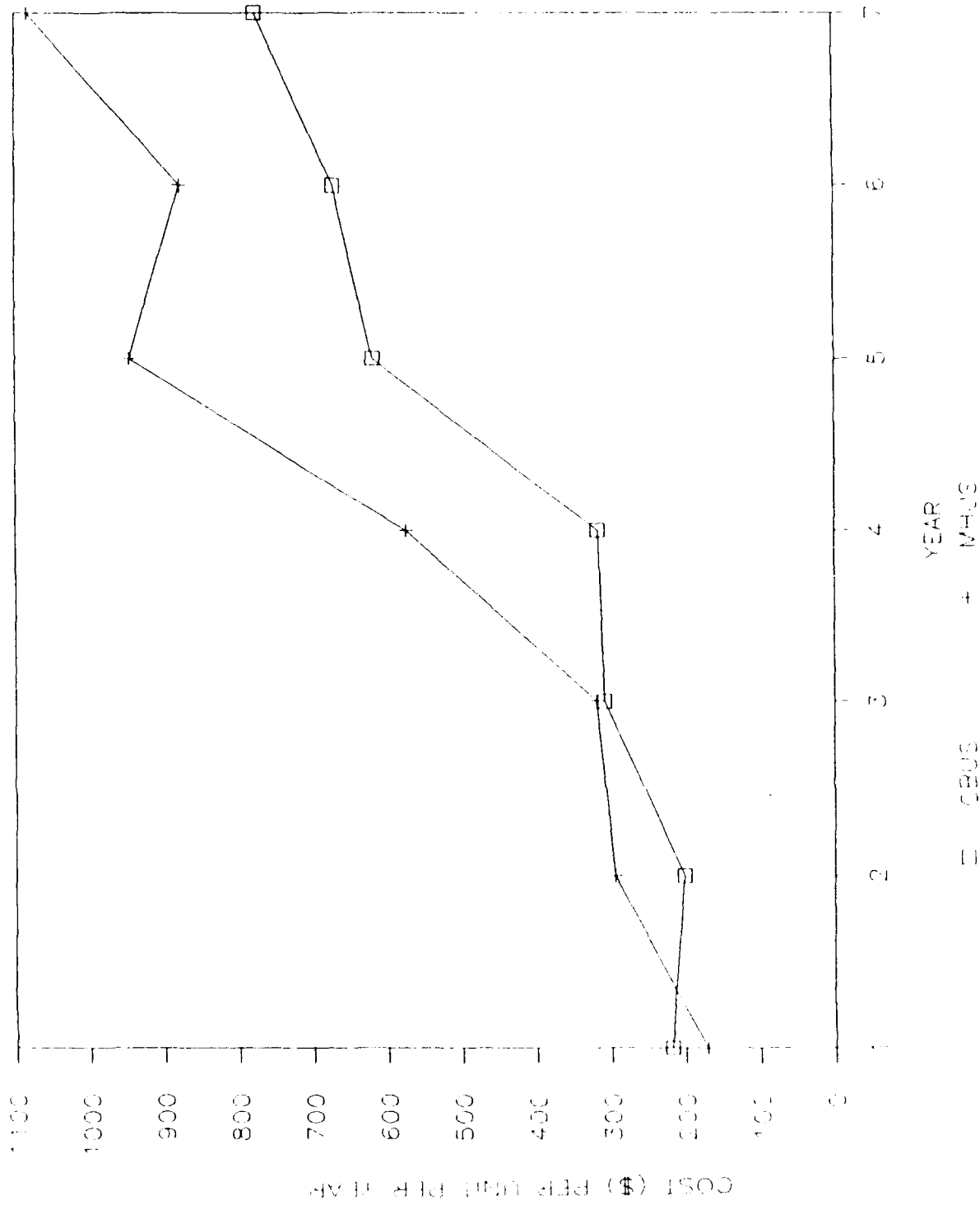


Figure 4. Total costs per unit per year.

**Table 3**  
**Interior Painting Costs**

Year	Total CBU (\$)	Cost/Unit (\$)	Total MHU (\$)	Cost/Unit (\$)
1	603	4	317	2
2	1,288	9	4,684	23
3	7,312	51	13,741	69
4	11,537	80	24,386	122
5	29,779	207	80,499	402
6	49,481	344	74,916	375
7	53,428	371	66,959	335
7-Year Total	153,428	152	265,502	190

**Table 4**  
**Yearly M&R Costs Excluding Interior Painting Costs**

Year	Total CBU (\$)	Cost/Unit (\$)	Total MHU (\$)	Cost/Unit (\$)
1	30,989	215	33,905	170
2	27,819	193	54,392	272
3	37,079	257	49,976	250
4	34,028	236	90,342	452
5	59,407	413	108,623	543
6	47,219	328	100,809	504
7	58,357	405	149,677	748

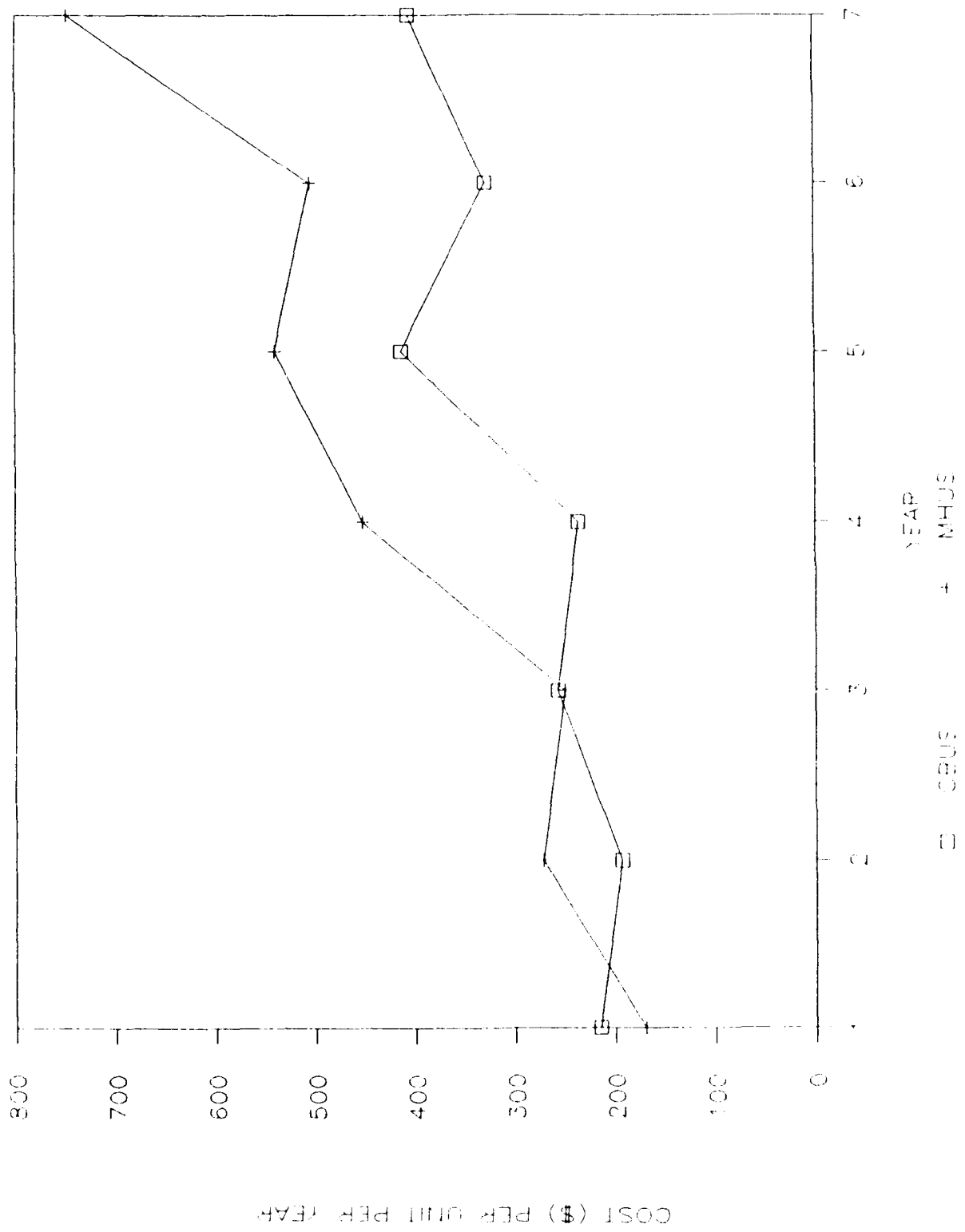


Figure 5. Costs per unit per year excluding interior painting costs.

**Table 5****Unit Costs Excluding Certain Equipment Costs**

<b>Year</b>	<b>Total CBU (\$)</b>	<b>Cost/Unit (\$)</b>	<b>Total MHU (\$)</b>	<b>Cost/Unit (\$)</b>
1	25,570	178	26,279	131
2	25,128	174	48,416	242
3	37,275	259	53,789	269
4	40,465	281	96,381	482
5	80,998	562	164,253	821
6	90,662	630	146,019	730
7	102,665	713	195,090	975
7-Year Total	402,754	400	730,227	522

**Table 6****Unit Costs Excluding Certain Equipment and Painting Costs**

<b>Year</b>	<b>Total Costs (\$)</b>		<b>Cost/Unit (\$)</b>	
	<b>CBU</b>	<b>MHU</b>	<b>CBU</b>	<b>MHU</b>
1	24,967	25,962	173	130
2	23,840	43,732	166	219
3	29,963	40,048	208	200
4	28,928	71,995	201	360
5	51,219	83,754	356	419
6	41,181	71,103	286	356
7	49,227	128,131	342	629
7-Year Total	249,326	464,726	247	332

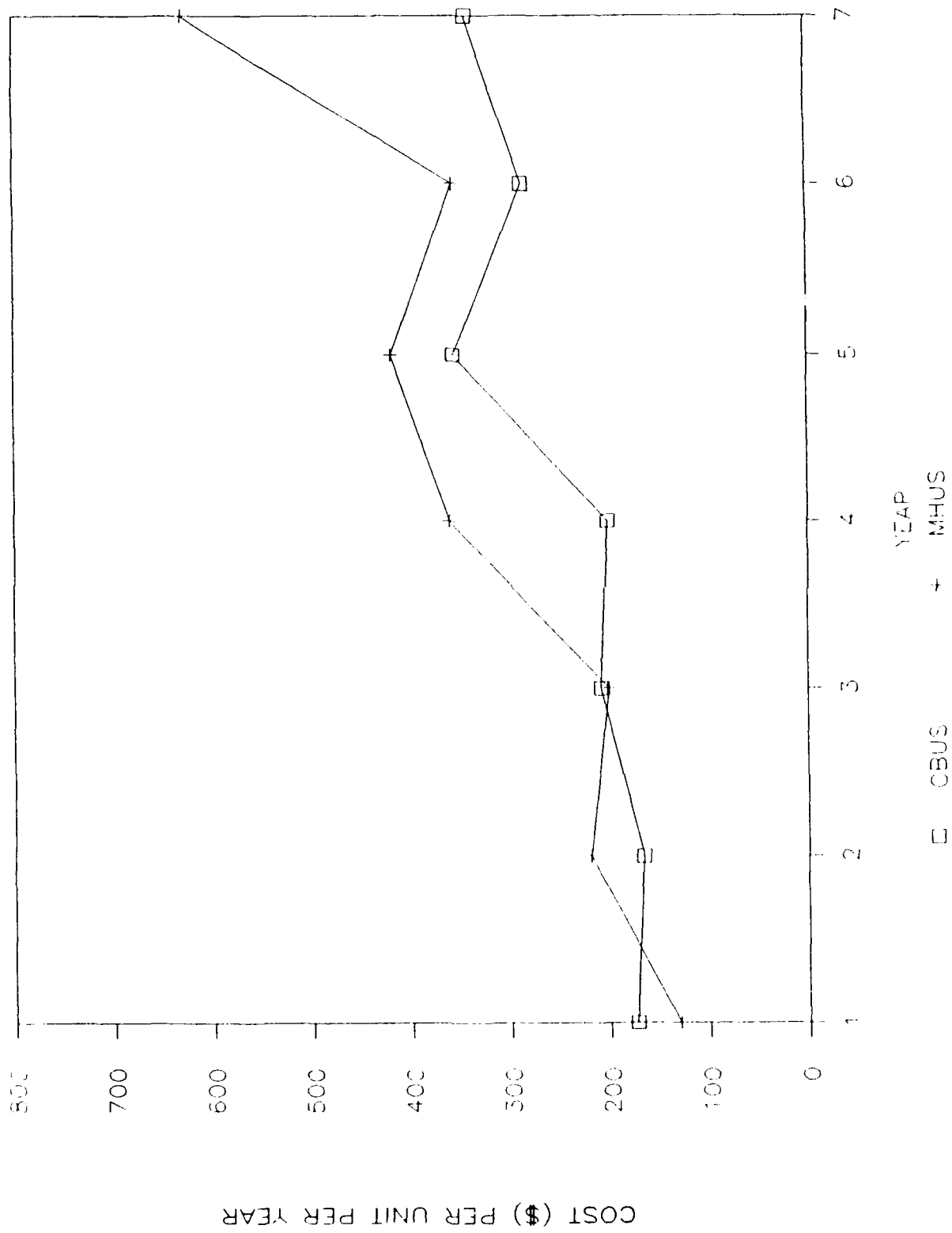


Figure 6. Costs per unit per year excluding certain equipment and painting costs.

**Table 7**  
**Component Actions and Work Orders\***

Year	MHU			CBU		
	Number Component Actions	Number WOs	Average Number WOs/Unit	Number Component Actions	Number WOs	Average Number WOs/Unit
1	1,718	1,610	8	1,139	1,128	8
2	1,938	1,371	7	989	863	6
3	2,183	1,273	6	1,404	877	6
4	4,048	1,867	9	1,592	869	6
5	3,735	2,028	10	2,920	1,335	9
6	3,830	2,116	11	2,506	1,247	9
7	<u>3,622</u>	<u>2,004</u>	<u>10</u>	<u>2,452</u>	<u>1,288</u>	<u>9</u>
Total	21,093	12,269	61	13,052	7,607	53

\*One work order (WO) may have several component repairs.

Note the \$17,767 cost for exterior-trim painting of MHUs and \$0 for CBUs. The exterior trim was to be painted on a cyclic basis. The CBU cycle in 1988 was deferred. Both CBU and MHU exterior-trim painting for 1989/90 was deferred.

Table 10 summarizes Table 9 data into the 12 major building component codes (Appendix C). Although the 0201-0220 structure is a high cost item, Table 9 shows most of these costs are related to doors and windows, and much of the damage to these items was occupant caused.

### Water Piping Problems

The manufacturer used polybutylene piping in the CBU units. The piping was installed in the building modules at the plant in Southern California and many connections made after the modules were assembled together at Fort Irwin (after 200 miles of transportation).

These manufactured apartments are two story fourplexes, two units above two units. Piping runs through walls, the ceiling of the first floor units (i.e., the floor of the second floor units) and under the first floor units in the crawl space.

There have been many leaks in the piping. There have been two major breaks in a "tee" joint in the ceiling of the first floor units of the MHUs. A detailed analysis of plumbing service orders shows a higher cost for MHUs for the category leaking or broken piping. Costs for each of the 7 years are shown in Table 11.

Table 8

## Maintenance Actions Performed and Costs Per Component

<u>Component</u>		<u>Maintenance/Repair Actions</u>				<u>Cost (\$)</u>			
<u>No.</u>	<u>Description</u>	<u>CBU</u>		<u>MHU</u>		<u>CBU</u>		<u>MHU</u>	
		(N=13,052)*		(N=21,093)		(Total=448,326)		(Total=853,168)	
101	Roofing surface	114	(1%)**	336	(2%)	9082	(2%)	30803	(4%)
103	Flashing, vents	22		13		488		490	
104	Gutters and downspouts	238	(2%)	314	(1%)	3591	(1%)	4707	(1%)
105	Other roof repairs	0		2		0		16	
201	Foundation and anchorage	3		2		24		24	
202	Structure	17		61		251		2039	
203	Insulation	3		0		42		0	
204	Masonry	10		10		240		260	
205	Exterior siding	4		2		207		238	
206	Exterior doors and frames	453	(3%)	811	(4%)	9331	(2%)	18260	(2%)
207	Storm and screen doors	608	(5%)	930	(4%)	18408	(4%)	33147	(4%)
208	Windows and frames	143	(1%)	206	(1%)	3053	(1%)	4541	(1%)
209	Storm windows and screens	302	(2%)	309	(1%)	6129	(1%)	5744	(1%)
210	Exterior trim	0		2		0		26	
211	Porch/deck	5		3		102		106	
212	Interior drywall	197	(2%)	401	(2%)	4746	(1%)	17616	(2%)
213	Wall coverings and paneling	12		0		200		0	
214	Interior doors	1194	(9%)	1354	(6%)	20633	(5%)	20428	(2%)
215	Interior casework	43		70		567		1125	
216	Bathroom accessories	170	(1%)	235	(1%)	2931	(1%)	2814	
217	Kitchen accessories, cabinets	308	(2%)	474	(2%)	4111	(1%)	7419	(1%)
218	Drapery hardware	17		89		268		1614	
219	Other exterior/interior	193	(1%)	293	(1%)	4968	(1%)	13692	(2%)
220	Garage doors	589	(5%)	455	(2%)	12284	(3%)	7917	(1%)
301	Resilient flooring	47		293	(1%)	1590		9788	(1%)
302	Carpet and pad	8		40		105		2720	
304	Underlayment/substrate	2		6		13		70	
305	Other flooring	25		98		940		15662	(2%)
401	Paint, walls and ceilings	243	(2%)	350	(2%)	150912	(34%)	259321	(30%)
402	Paint, trim	1		0		20		0	
403	Paint, touchup, interior	63		171	(1%)	1703		5262	(1%)
404	Bathtub, shower caulking	203	(2%)	347	(2%)	2241		4413	(1%)
405	Other interior painting	34		20		792		918	
501	Paint, exterior walls	3		3		92		45	
502	Paint, exterior doors, frames	5		4		138		79	
503	Paint, exterior trim	0		13		0		17767	(2%)
504	Exterior caulking	0		1		0		20	
506	Other exterior painting	2		3		44		75	

\*N = Number of maintenance actions

\*\*Percents are given for number maintenance actions and costs when the value is 1% or more of the total.

Table 8 (Cont'd)

<u>Component</u>		<u>Maintenance/Repair Actions</u>			<u>Cost (\$)</u>	
<u>No.</u>	<u>Description</u>	<u>CBU</u>	<u>MHU</u>	<u>CBU</u>	<u>MHU</u>	
601	Heating plant, valve	102 (1%)	55	3617 (1%)	2855	
602	Motors, blowers, pumps	60	83	4277 (1%)	5529 (1%)	
603	Ducts	1	25	15	1225	
604	Piping	7	2	190	23	
605	Diffusers, grills	13	65	202	920	
606	Insulation	0	2	0	61	
607	Heating controls	139 (1%)	99	6073 (1%)	4374 (1%)	
608	Other heating	475 (4%)	733 (3%)	6630 (1%)	11166 (1%)	
701	Cooling coils, compressor	43	44	8065 (2%)	2386	
702	A/C motors, blowers, pumps	96 (1%)	117 (1%)	7172 (2%)	5928 (1%)	
703	A/C piping, ducting	6	38	160	1157	
704	A/C refrigerant	391 (3%)	204 (1%)	13761 (3%)	6996 (1%)	
705	A/C insulation	1	0	7	0	
706	A/C controls	99 (1%)	82	4242 (1%)	3126	
707	Other cooling	573 (4%)	815 (4%)	12671 (3%)	16796 (2%)	
801	Water heater	254 (2%)	473 (2%)	5626 (1%)	14542 (2%)	
803	Piping, supply	107 (1%)	575 (3%)	3216 (1%)	25554 (3%)	
804	Faucets and shower heads	562 (4%)	1409 (7%)	12476 (3%)	32180 (4%)	
805	Lavatories	308 (2%)	839 (4%)	4729 (1%)	21439 (3%)	
806	Water closets	655 (5%)	1039 (5%)	11732 (3%)	19249 (2%)	
807	Bathtub/shower unit	97 (1%)	371 (2%)	1555	7830 (1%)	
809	Other plumbing	182 (1%)	426 (2%)	3672 (1%)	10635 (1%)	
901	Service entrance	2	2	65	188	
902	Panel box/circuit breakers	62	155 (1%)	1949	5811 (1%)	
903	Branch circuits	19	21	532	1358	
904	Wall receptacles	282 (2%)	485 (2%)	4342 (1%)	8810 (1%)	
905	Doorbells and chimes	1	1	15	4	
906	Light fixtures	1211 (9%)	1189 (6%)	20270 (5%)	22140 (3%)	
907	Vents, fans	35	47	656	926	
908	Other electrical	38	42	872	2901	
1001	Garbage disposal	318 (2%)	648 (3%)	6011 (1%)	14086 (2%)	
1002	Dishwasher	298 (2%)	888 (4%)	16133 (4%)	60845 (7%)	
1003	Range	697 (5%)	1125 (5%)	15149 (3%)	21166 (2%)	
1004	Range hood	64	65	955	824	
1005	Refrigerator	97 (1%)	384 (2%)	1717	11478 (1%)	
1006	Other equipment	146 (1%)	222 (1%)	1450	2341	
1201	Water supply	75 (1%)	133 (1%)	1928	3964	
1202	Gas supply	78 (1%)	120 (1%)	2318 (1%)	3235	
1203	Electrical service	50	75	1636	6757 (1%)	
1204	Sanitary/sewer lines	5	4	657	191	
1205	Other utility service	0	1	0	8	
1300	Miscellaneous	122 (1%)	270 (1%)	1316	3000	

Table 9

## Maintenance Costs Per Component, Adjusted by Number of Units

Component No.	Description	CBU	Costs (\$)			
			MHU	MHU Adjusted*	CBU/144**	MHU/200**
101	Roofing surface	9082	30803	22178	63.07	154.02
103	Flashing, vents	488	490	353	3.39	2.45
104	Gutters and downspouts	3591	4707	3389	24.94	23.54
105	Other roof repairs	0	16	12	0.00	0.08
201	Foundations and anchorage	24	24	17	0.17	0.12
202	Structure	251	2039	1468	1.74	10.20
203	Insulation	42	0	0	0.29	0.00
204	Masonry	240	260	187	1.67	1.30
205	Exterior siding	207	238	171	1.44	1.19
206	Exterior doors and frames	9331	18260	13147	64.80	91.30
207	Storm and screen doors	18408	33147	23866	127.83	165.74
208	Windows and frames	3053	4541	3270	21.20	22.71
209	Storm windows and screens	6129	5744	4136	42.56	28.72
210	Exterior trim	0	26	19	0.00	0.13
211	Porch/deck	102	106	76	0.71	0.53
212	Interior drywall	4746	17616	6426	32.96	88.08
213	Wall coverings and paneling	200	0	0	1.39	0.00
214	Interior doors	20633	20428	12684	143.28	102.14
215	Interior casework	567	1125	810	3.94	5.63
216	Bathroom accessories	2931	2814	2026	20.35	14.07
217	Kitchen accessories, cabinets	4111	7419	5342	28.55	37.10
218	Drapery hardware	268	1614	1162	1.86	8.07
219	Other exterior/interior	4968	13692	9858	34.50	68.46
220	Garage doors	12284	7917	5700	85.31	39.59
301	Resilient flooring	1590	9788	7047	11.04	48.94
302	Carpet and pad	105	2720	1958	0.73	13.60
304	Underlayment/substrate	13	70	50	0.09	0.35
305	Other flooring	940	15662	11277	6.53	78.31
401	Paint, walls and ceilings	150912	259321	186711	1048.00	1296.61
402	Paint, trim	20	0	0	0.14	0.00
403	Paint, touchup, interior	1703	5262	3789	11.83	26.31
404	Bathtub, shower caulking	2241	4413	3177	15.56	22.07
405	Other interior painting	792	918	661	5.50	4.59
501	Paint, exterior walls	92	45	32	0.64	0.23
502	Paint, exterior doors, frames	138	79	57	0.96	0.40
503	Paint, exterior trim	0	17767	12791	0.00	88.84
504	Exterior caulking	0	20	14	0.00	0.10
506	Other exterior painting	44	75	54	0.31	0.38
601	Heating plant, valve	3617	2855	2056	25.12	14.28
602	Motors, blowers, pumps	4277	5529	3981	29.70	27.65

\*The MHU/ column adjusted by multiplying by 0.72.

\*\*These are costs per unit for the 7 years.

Table 9 (Cont'd)

<u>No.</u>	<u>Description</u>	<u>Costs (\$)</u>				
		<u>CBU</u>	<u>MHU</u>	<u>Adjusted</u>	<u>CBU/144</u>	<u>MHU/200</u>
603	Ducts	15	1225	882	0.10	6.13
604	Piping	190	23	17	1.32	0.12
605	Diffusers, grills	202	920	662	1.40	4.60
606	Insulation	0	61	44	0	0.31
607	Heating controls	6073	4374	3149	42.17	21.87
608	Other heating	6630	11166	8040	46.04	55.83
701	Cooling coils, compressor	8065	2386	1718	56.01	11.93
702	A/C motors, blowers, pumps	7172	5928	4268	49.81	29.64
703	A/C piping, ducts	160	1157	833	1.11	5.79
704	A/C refrigerant	13761	6996	5037	95.56	34.98
705	A/C insulation	7	0	0	0.05	0.00
706	A/C controls	4242	3126	2251	29.46	15.63
707	Other cooling	12671	16796	12093	87.99	83.98
801	Water heater	5626	14542	10470	39.07	72.71
803	Piping, supply	3216	25554	18399	22.33	127.77
804	Faucets and shower heads	12476	32180	23170	86.64	160.90
805	Lavatories	4729	21439	15436	32.84	107.20
806	Water closets	11732	19249	13859	81.47	96.25
807	Bathtub/shower unit	1555	7830	5638	10.80	39.15
809	Other plumbing	3672	10635	7657	25.50	53.18
901	Service entrance	65	188	135	0.45	0.94
902	Panel box/circuit breakers	1949	5811	4184	13.53	29.06
903	Branch circuits	532	1358	978	3.69	6.79
904	Wall receptacles	4342	8810	6343	30.15	44.05
905	Doorbells and chimes	15	4	3	0.10	0.02
906	Light fixtures	20270	22140	15941	140.76	110.70
907	Vents, fans	656	926	667	4.56	4.63
908	Other electrical	872	2901	2089	6.06	14.51
1001	Garbage disposal	6011	14086	10142	41.74	70.43
1002	Dishwasher	16133	60845	43808	112.03	304.23
1003	Range	15149	21166	15240	105.20	105.83
1004	Range hood	955	824	593	6.63	4.12
1005	Refrigerator	1717	11478	8264	11.92	57.39
1006	Other equipment	1450	2341	1686	10.07	11.71
1201	Water supply	1928	3964	2854	13.39	19.82
1202	Gas supply	2318	3235	2329	16.10	16.18
1203	Electrical service	1636	6757	4865	11.36	33.79
1204	Sanitary/sewer lines	657	191	138	4.56	0.96
1205	Other utility service	0	8	6	0.00	0.04
1300	Miscellaneous	1316	3000	2160	9.14	15.00
	Totals	448,326	853,168	614,281		

Table 10

Maintenance Actions Performed and Costs for Component Group, 7-Year Summary

Component Group	Description	Maintenance/Repair Actions		Cost (\$)		MHU Adjusted
		CBU	MHU	CBU	MHU	
		(N=13,052)	(N=21,093)	(Total = 448,326)	(Total = 853,168)	(Total = 614,281)
0101-0105	Roofing	374 (3%)	665 (3%)	13,161 (3%)	36,016 (4%)	25,932
0201-0220	Structure	4,271 (33%)	5,707 (27%)	88,516 (20%)	137,007 (16%)	98,645
0301-0305	Floor coverings	82 (1%)	437 (2%)	2,648 (1%)	28,240 (3%)	20,333
0401-0405	Interior painting	544 (4%)	888 (4%)	155,668 (35%)	269,914 (32%)	194,338
0501-0506	Exterior painting	10 (0%)	24 (0%)	274 (0%)	17,986 (2%)	12,950
0601-0608	Heating	797 (6%)	1064 (5%)	21,003 (5%)	26,153 (3%)	18,830
0701-0707	Air conditioning	1,209 (9%)	1,300 (6%)	46,077 (10%)	36,390 (4%)	26,201
0801-0809	Plumbing	2,165 (17%)	5,132 (24%)	43,006 (10%)	131,429 (15%)	94,629
0901-0908	Electrical	1,650 (13%)	1,942 (9%)	28,701 (6%)	42,138 (5%)	30,339
1001-1006	Equipment	1,620 (12%)	3,332 (16%)	41,416 (9%)	110,741 (13%)	79,734
1201-1205	Utility service	208 (2%)	333 (2%)	6,539 (1%)	14,154 (2%)	10,191
1300	Miscellaneous	122 (1%)	270 (1%)	1316 (0%)	3,000 (0%)	2,160

Table 11

Water Piping Costs

Year	CBUs (\$)	MHUs (\$)
1	776	1,134
2	473	2,524
3	408	758
4	408	1,769
5	108	2,462
6	487	4,870
7	557	12,036
Total	3,216	25,554

Most leaks are breaks of the "hard plastic" tees and valves, usually under the crimped metal band. The Fort Irwin DEH thinks it is so bad that they want to replace all piping. They are contracting the replacement in one building to develop the methods and to get a better idea of the cost. As this report is being written a special study of the problem is being initiated.

This is not a new problem in the plastic pipe industry. A "60 minutes" television program shown in December 1990, described many problems in the Southwest with such materials. The companies paid required repairs because the plastic material itself was defective. A question to be answered is whether the same defective material was used at Fort Irwin.

### Impact of Inflation on Comparisons

All of the costs in Table 10 were charged at the time of occurrence. There was about a 1-year difference between the two types of units since the CBUs were occupied about 1 year earlier than the MHUs. To assess the impact of inflation on the overall comparisons, costs were all converted to 1990 prices by multiplying total costs in a given year by that year's inflation factor. Inflation factors for the years 1983 through 1990 were determined from "The Home Maintenance and Repair Index" in the *Economic Report of the President* (Table B-59, Consumer Price Indexes, selected classes, 1946-1990, Jan 90). The yearly indices and inflation factors used in this study are shown below:

<u>Year</u>	<u>Index</u>	<u>Inflation Factor</u>
1991	126.0 (est)	1.000
1990	122.2	1.031
1989	118.0	1.068
1988	114.7	1.099
1987	111.8	1.127
1986	107.9	1.168
1985	106.5	1.183
1984	103.7	1.215
1983	99.9	1.261

Figure 7 shows cumulative inflated costs per unit over time. This is the same graph as that in Figure 2, except that the costs are inflated. Note that the difference between the two types at the end of 5 years was about the same, but the magnitude of both had increased. This can also be seen in Table 12.

The difference for cost/unit/year is \$160 for actual costs and \$162 for inflated costs. Thus, there is no difference in the two comparisons.

MONTHS 15-84

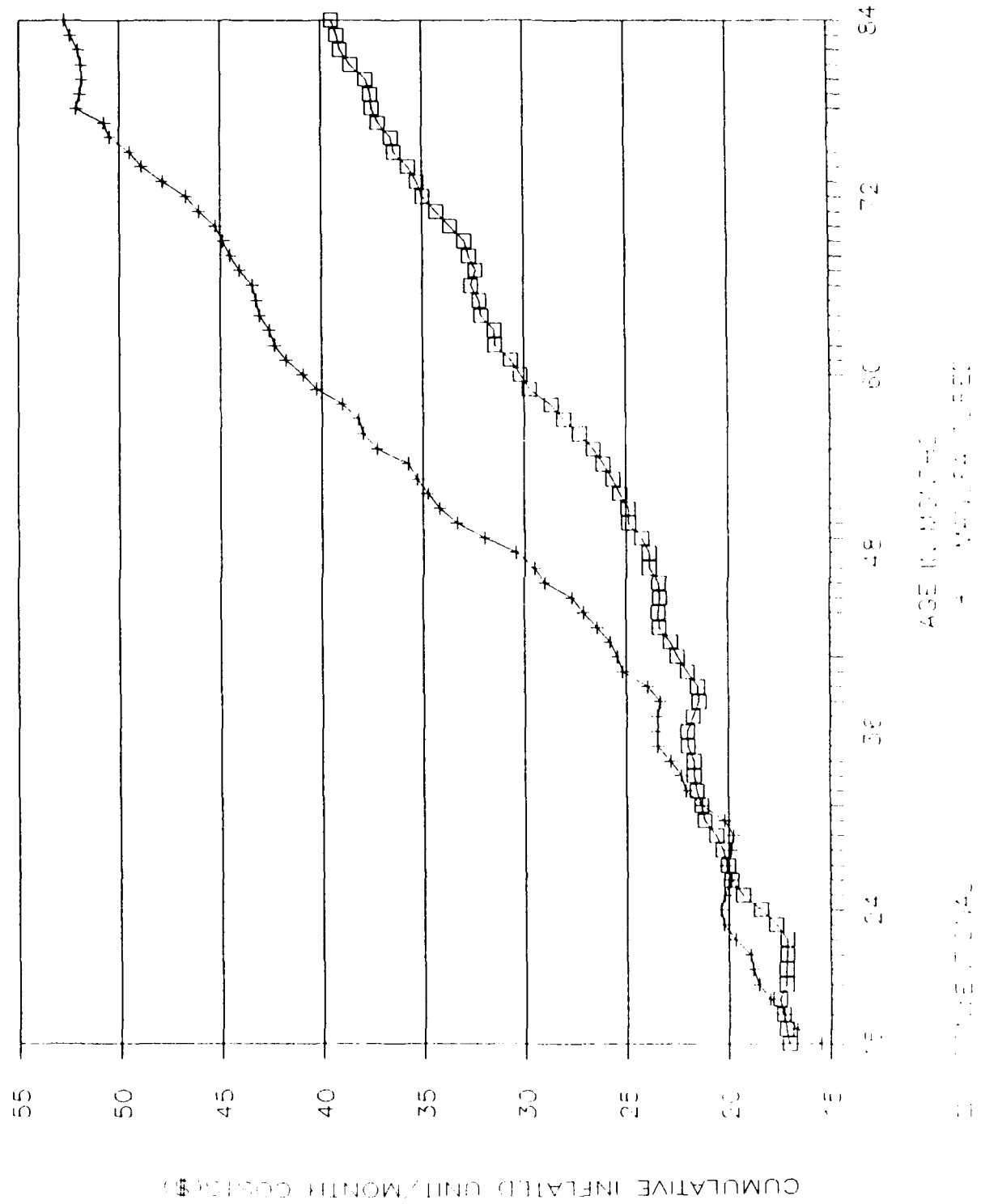


Figure 7. Cost per unit per month over time, adjusted for inflation.

Table 12

Comparison of Actual and Inflated Costs

Type	No. Unit Months	Total Cost (\$)	Cost/Unit/ Month (\$)	Cost/Unit/ Year (\$)
CBU	12,096	448,326	37.06	445
CBU-Infl	12,096	497,568	41.13	494
MHU	16,800	853,168	50.78	609
MHU-Infl	16,800	918,437	54.67	656

## **7 ENERGY COSTS**

Comparisons of gas and electricity consumption began in May 1984, since most MHUs were not occupied before then.

### **Electricity Consumption**

The average quarterly usage (kWh) per housing unit is shown in Table 13. The MHUs had higher average consumptions than the CBUs in 14 of the 28 quarters and always higher in the summer quarter, Jun-Aug. For the entire 84-month data collection period, an MHU used an average total of 64,072 kWh, while a CBU used an average total of 63,020 kWh. This was a difference of 1,052 kWh ÷ 84 months = 12.52 kWh/month. At the August 1991 rate of \$0.0712/kWh, an MHU cost \$0.89 more than a CBU for electricity per month.

### **Gas Consumption**

The type of fuel used was liquid propane (LP). LP is delivered to a central facility on post and is converted to gas and distributed to housing units through underground pipes. The average quarterly usage (cu ft) per housing unit is shown in Table 14.

For the 84-month period, an MHU used an average total of 136,560 cu ft while a CBU used an average total of 127,078 cu ft. The MHUs had higher average consumptions in 23 of the quarters, always higher in the winter, Dec-Feb, and spring, Mar-May, quarters. This is a difference of 9,482 cu ft ÷ 84 months = 113 cu ft/month. At the August 1991 cost of \$0.01446/cu ft an MHU cost \$1.63 more than a CBU for gas per month.

### **Total Energy Consumption**

The total energy consumption for the housing units is shown in Table 15. It was calculated by converting the gas and electricity consumption data to MBTU/KSF. (One cubic foot of propane gas = 2618.5 BTU and one kWh of electricity = 3413 BTU.) The area of the housing units is approximately 950 sq ft, so a multiplier of  $1000/950 = 1.053$  was used to convert usage to kilowatts per square foot.

### **Cost Comparison Summary**

The averages for dwelling unit energy consumption and cost for the 7-year period (May 1984 to April 1991) are given in Table 16. The MHUs on the average have cost \$30 more per year for gas and electricity than the CBUs.

### **Meter Problems**

Many meters have become defective over the past 7 years. For the CBUs 39 electric and nine gas meters have failed while for the MHUs 19 electric and four gas have failed.



Table 14

## Average Quarterly Gas Consumption (1 cu ft) Per Housing Unit

	1984 Jun-Aug	Sep-Nov	1984-5 Dec-Feb	1985 Mar-May	Jun-Aug	Sep-Nov	1985-6 Dec-Feb	1986 Mar-May
MHU	1890	4400	10050	5130	1890	4440	7670	4020
CBU	1780	3730	9200	4500	1840	3970	7080	3950
	1986 Jun-Aug	Sep-Nov	1986-7 Dec-Feb	1987 Mar-May	Jun-Aug	Sep-Nov	1987-8 Dec-Feb	1988 Mar-May
MHU	1800	3810	9340	4390	1910	3300	9930	4740
CBU	2130	3520	9070	4500	2160	3430	9500	4460
	1988 Jun-Aug	Sep-Nov	1988-9 Dec-Feb	1989 Mar-May	Jun-Aug	Sep-Nov	1989-90 Dec-Feb	1990 Mar-May
MHU	1880	3490	10000	3700	1940	3370	9150	4010
CBU	1960	3250	9400	3550	1960	3140	8160	3390
	1990 Jun-Aug	Sep-Nov	1990-1 Dec-Feb	1991 Mar-May				
MHU	1850	3350	9210	6070				
CBU	1790	2920	7810	4950				

**Table 15**  
**Total Energy Consumption**

	<u>MHU</u>		<u>CBU</u>	
	Elect	Gas	Elect	Gas
84 month total	64,072 kWh	136,560 CF	63,020 kWh	127,078 CF
Yearly average	9,153 kWh	19,509 CF	9,003 kWh	118,154 CF
MBTU/year	31.24	51.08 MBTU	30.73 MBTU	47.54 MBTU
Total energy per year		82.32 MBTU		78.27 MBTU
Conversion to MBTU/ksq ft		86.68 MBTU/yr		82.41 MBTU/yr

(MBTU = million British thermal units, CF = cubic feet)

**Table 16**  
**Seven-Year Summary of Energy Consumption**

Unit	MHU		CBU	
	Gas	Electricity	Gas	Electricity
Average Consumption/Year Per Housing Unit	19,509	9,153 kWh	18,154 cu ft	9,003 kWh
Average Cost/Year Per Housing Unit	\$282	\$652	\$263	\$641
Total Cost/Year		\$934		\$904

### Comments

The data in Chapter 5 (better air tightness and higher furnace efficiencies for the MHUs) would indicate the MHUs should use less energy than the CBUs. However, this is offset by the higher overall heat loss of the MHUs. Detailed energy simulations (performed using the Building Loads Analysis and System Thermodynamics\* program) indicate two design/construction features that cause the higher wall-heat loss: the MHUs have more window/door glass area; and the MHUs have single-pane glass while the CBUs have thermal-pane. Additionally, the CBUs were built on concrete slabs while the MHUs have crawl spaces, which are less energy efficient.

\*The Building Loads Analysis and System Thermodynamics (BLAST) program was developed by USACERL and is used throughout the Department of Defense for military construction projects.

## 8 CONCLUSIONS AND RECOMMENDATIONS

### Maintenance Costs

After 7 years' occupancy, there is a difference in maintenance costs between the two types of units. The MHUs cost \$122 more per unit for maintenance (ignoring equipment costs, such as ranges and dishwashers). This is a 30.5 percent difference in costs (\$522/year for MHU vs. \$400/year for CBU).

### Energy Costs

MHUs cost more than CBUs for energy used—\$30 more per unit per year for gas and electricity.

### Total O&M Costs

The total difference in O&M costs is \$152/year/unit (11.7 percent) (based on \$1304/year for CBUs ignoring equipment costs.)

The maintenance cost difference of 30.5 percent, combined with the overall trend for MHU costs to increase at a faster rate, indicates that the maintenance cost difference may well become very large.

### Trends

A problem is developing with the MHU water piping. Piping failures are not only significantly increasing in cost, but also in impacting the morale of families in units with major problems. If all piping has to be replaced there will be a very significant difference to the government in costs between the two types of construction.

It is recommended data collection continue for another year, and that the causes of the MHU water piping problem and the resultant cost to the government be investigated.

## APPENDIX A: DESCRIPTION OF THE MHU CONSTRUCTION PROCESS

The MHUs were not typical of manufactured housing in that the manufacturer was not allowed to design the housing. Instead the contractor was given designs based on the fourplexes being built using conventional construction methods and was required to manufacture accordingly. Thus, it is possible that given the opportunity to both design and manufacture, the final structure might be somewhat different and less costly.

The concept used was to manufacture complete modules in the factory which could be transported (about 200 miles from the factory in the Los Angeles area to Fort Irwin) and assembled on site. Thus, the process involved several steps: manufacture of complete modules (electrical, plumbing, HVAC, etc., included at the plant); construction of perimeter footings at the site; transportation of modules to the site; assembly of the modules into fourplexes using a crane; joining modules together including connection of piping and electrical wiring; application of stucco exterior finish; roofing at the module joints and securing of eaves; and on-site construction of the garages. On-site construction was limited by contract to foundations, utilities, slabs, garages, exterior finishes, final painting, exterior stairways and balconies. Figures A1 through A6 show factory work, modules on trucks, crane assembly and a completed fourplex without stucco and garages.

As is discussed in Chapter 10, the eaves were attached using flat metal straps and folded onto the roof for transportation (this decreased the width for highway transportation). Upon assembly at the site, the eaves were folded down and secured with only a few nails. This was a defect in the design/construction, as the eaves began to loosen and one actually fell to the ground. All eaves were then permanently secured at a cost of over \$6000 per building.

The MHUs are essentially the same as the CBUs; floor plans of the two types are very similar. Figures A7 through A10 show sample floor plans for the MHUs and the CBUs.

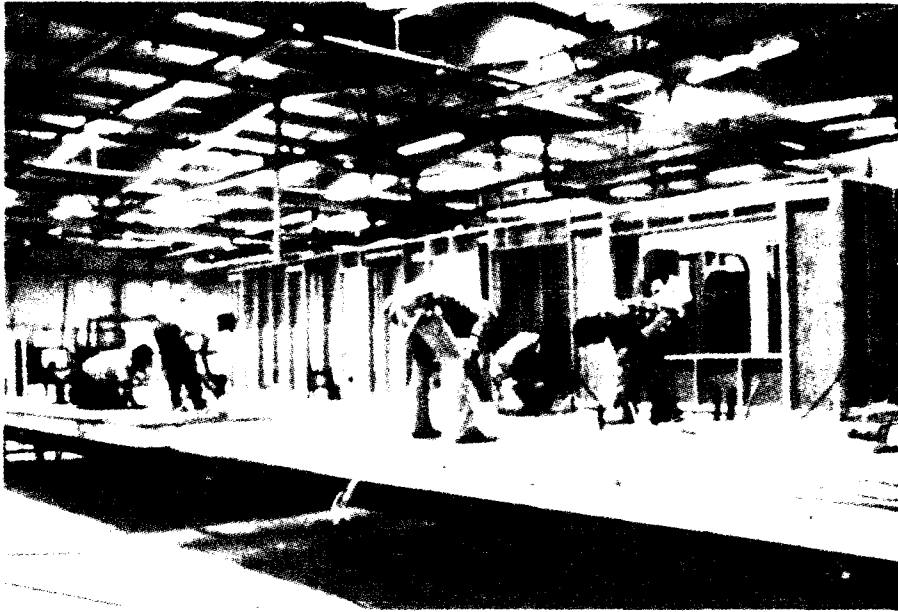


Figure A1. Construction in the factory.

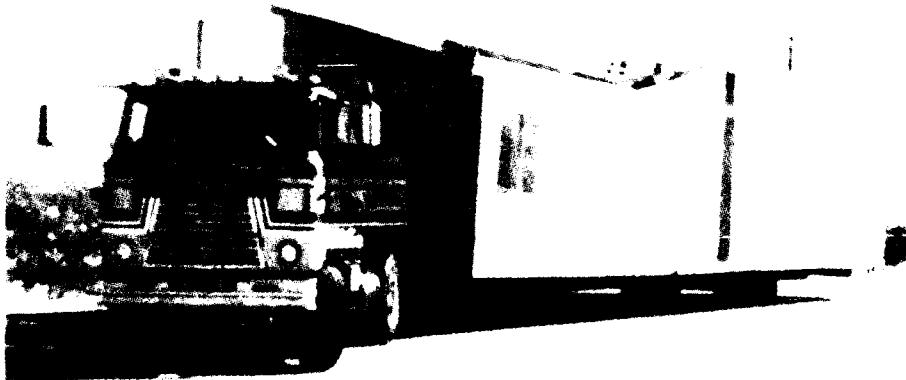


Figure A2. Two modules loaded on truck.

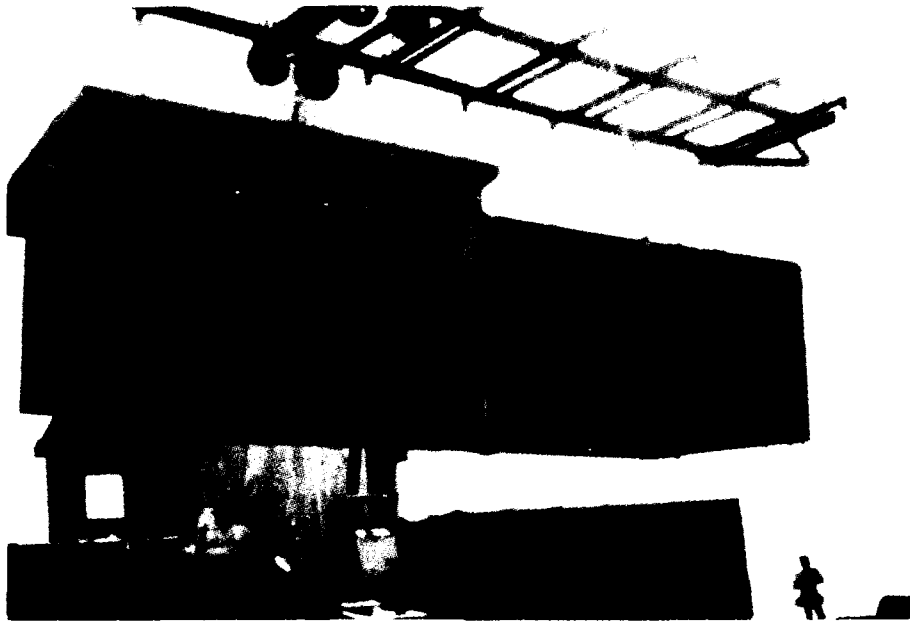


Figure A3. Module being set in place by crane.

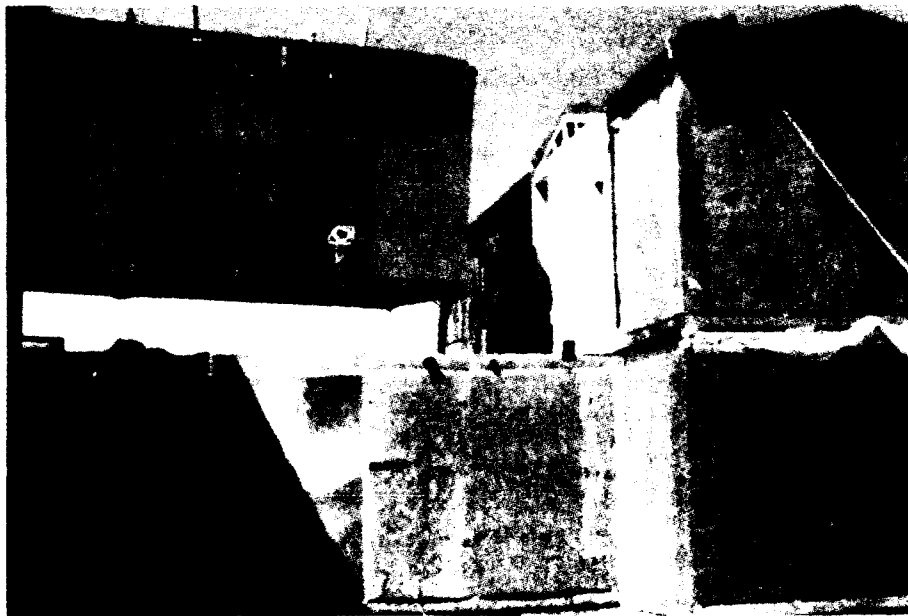


Figure A4. Near completion of one building.



Figure A5. Completed assembly of modules.



Figure A6. Overview of buildings without garages.

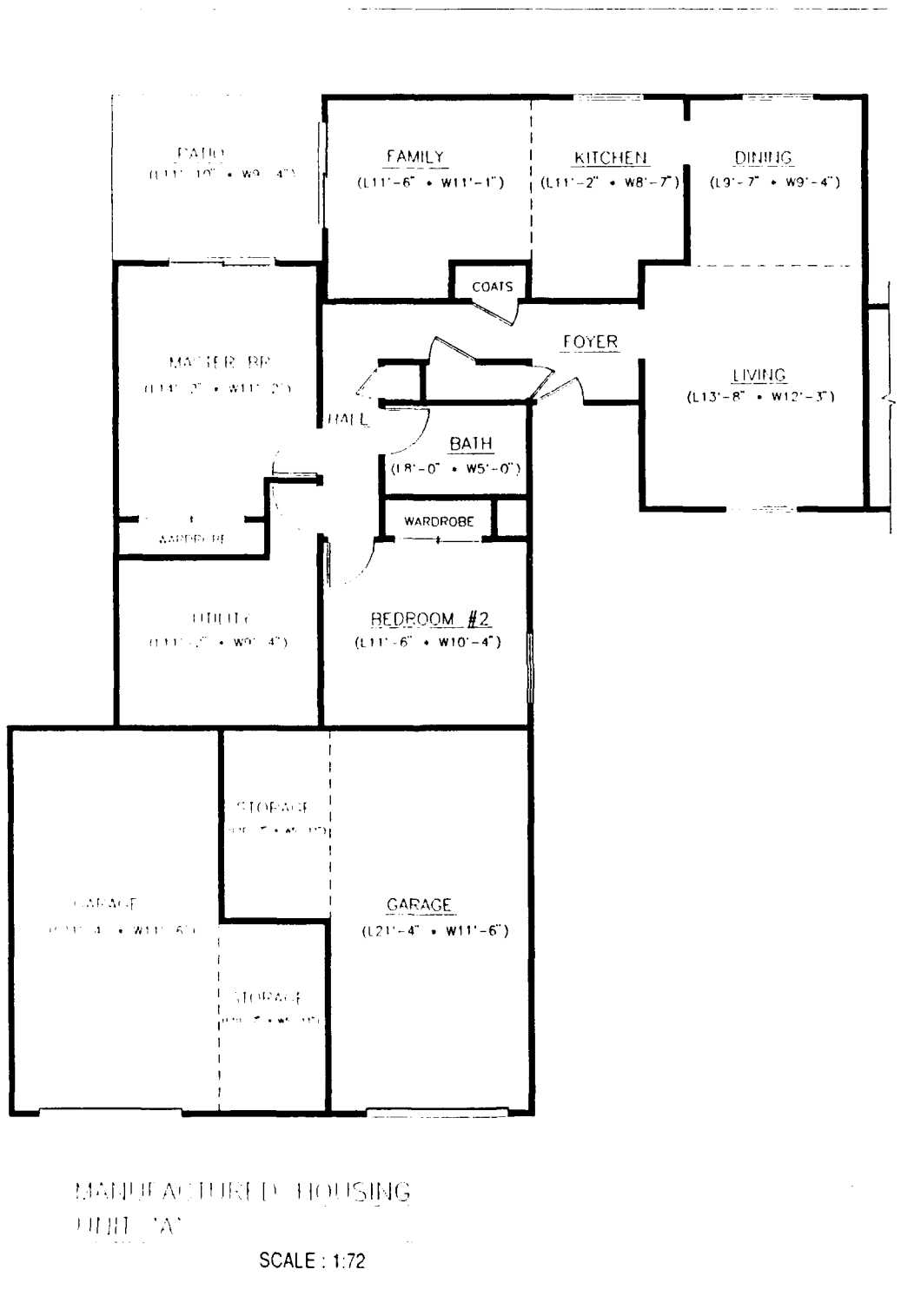


Figure A7. Floor plan for first floor MHU, Type A.

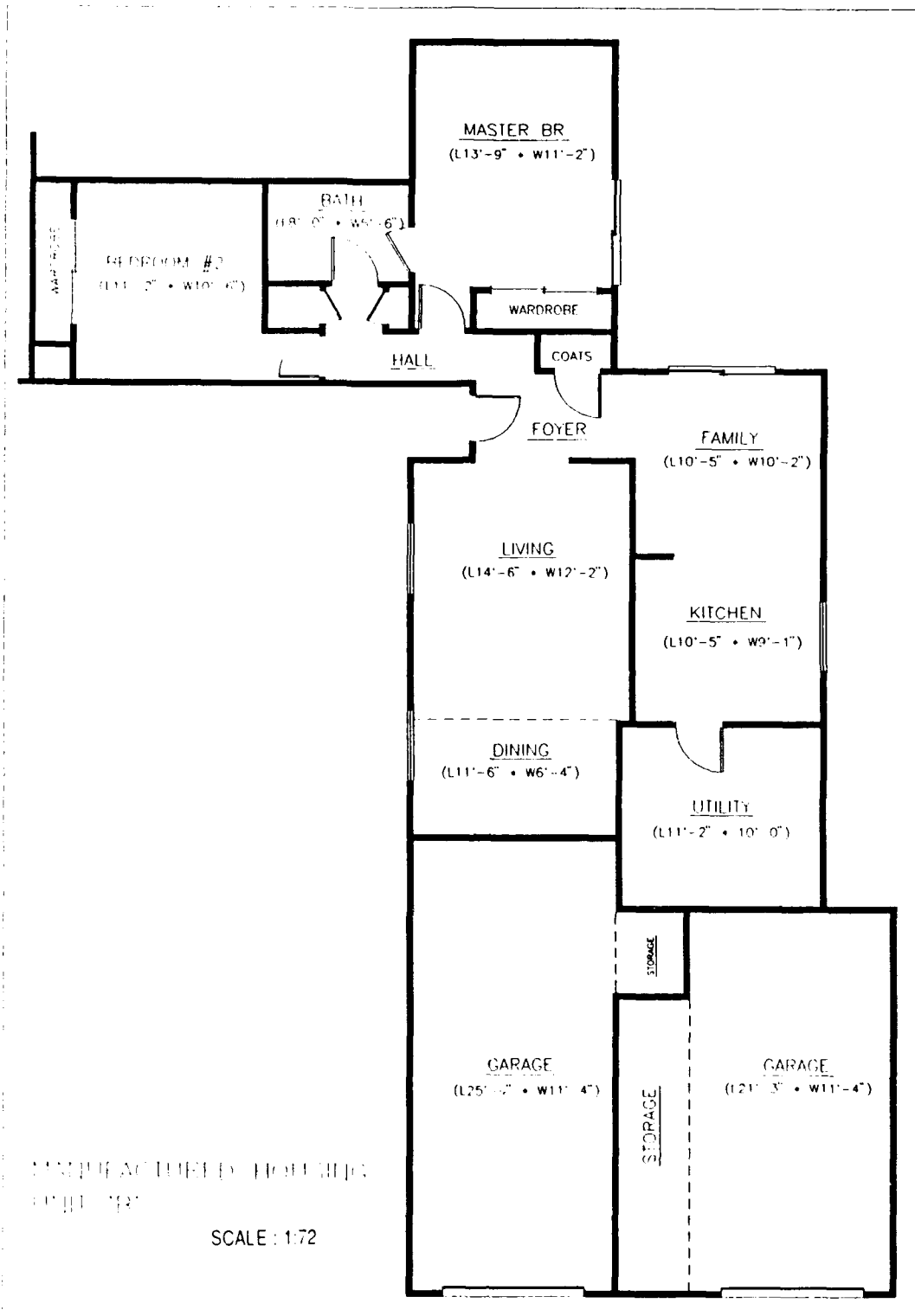


Figure A8. Floor plan for first floor MHU, Type B.

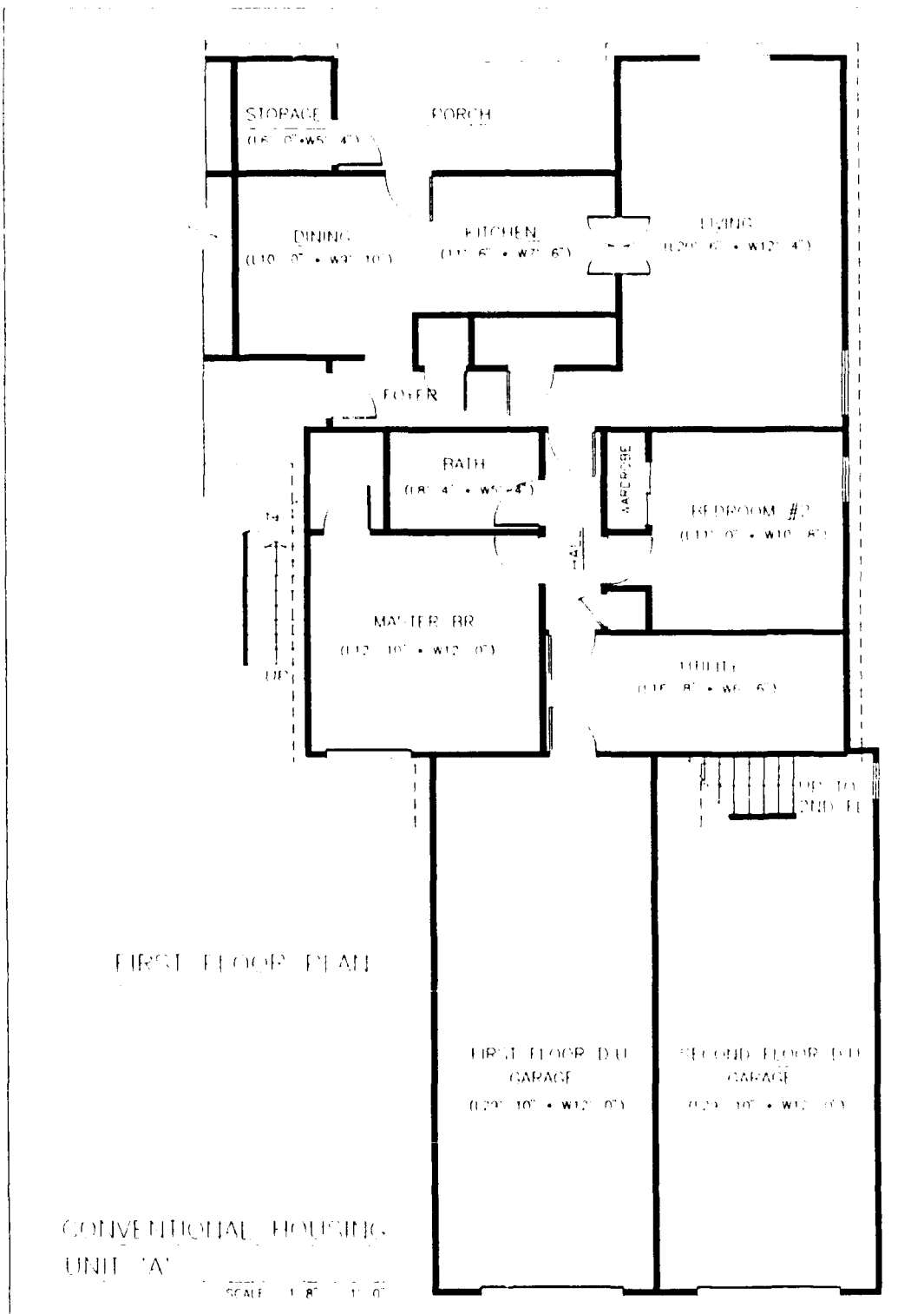
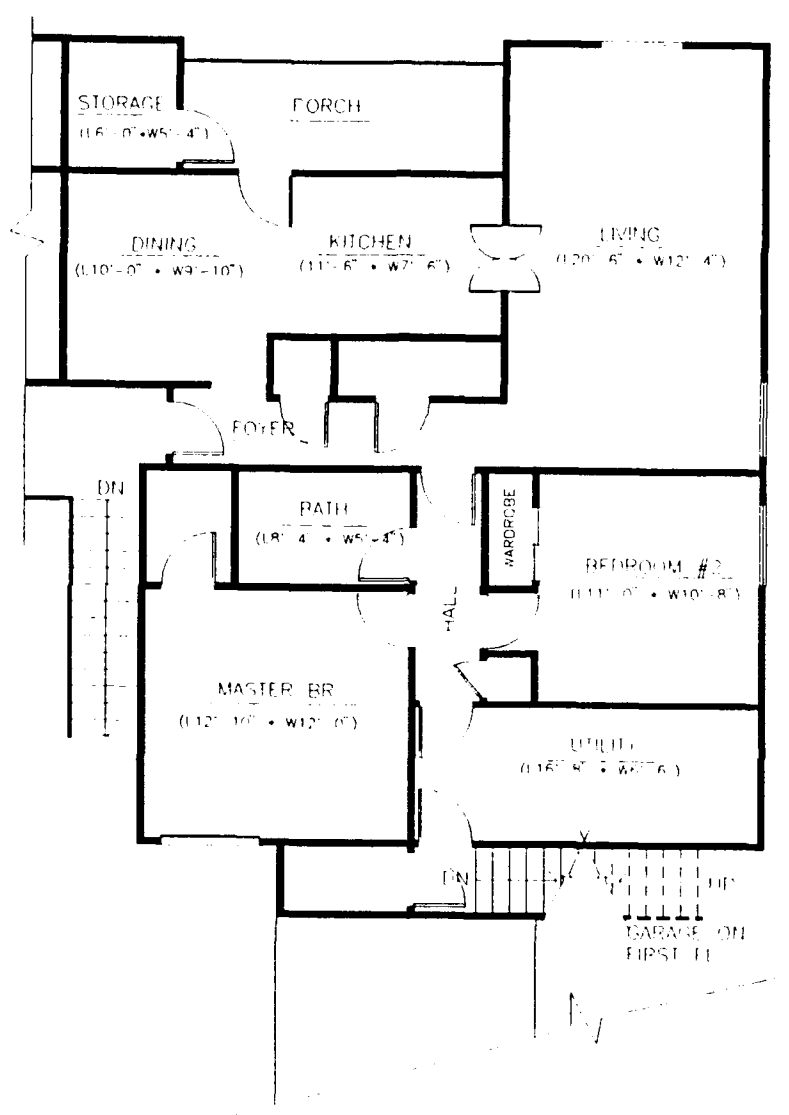


Figure A9. Floor plan for first floor CBU, Type A.



SECOND FLOOR PLAN

CONVENTIONAL TRIPHASE  
 UNIT 'A'

Figure A10. Floor plan for second floor CBU, Type A.

**APPENDIX B: LIST OF HOUSING UNITS**

**Conventionally Built**

3680 A-F	3705 A-E	3727 A-E
3681 A-D	3712 A-F	3731 A-D
3684 A-D	3715 A-F	3732 A-F
3685 A-F	3720 A-F	3738 A-F
3690 A-F	3721 A-E	3742 A-D
3691 A-D	3722 A-E	3743 A-F
3693 A-F	3723 A-E	3745 A-F
3694 A-D	3724 A-D	3747 A-D
3695 A-D	3725 A-E	3750 A-F
3700 A-F		

**Manufactured (Each with four apartments, A-D)**

3800	3821	3841
3801	3822	3842
3802	3823	3843
3803	3824	3844
3804	3825	3845
3805	3826	3846
3806	3827	3848
3807	3828	3850
3809	3829	3851
3811	3831	3852
3812	3832	3853
3813	3833	3854
3814	3834	3855
3815	3835	3856
3816	3837	3857
3818	3839	3858
3820	3840	

## APPENDIX C: BUILDING COMPONENT/SUBCOMPONENT CODES

### 01 Roofing

0101	Roofing surface
0102	Fasteners
0103	Flashing, vents, protrusions
0104	Gutter and downspouts
0105	Other roof repairs

### 02 Structure

0201	Foundation and anchorage
0202	Structure, incl. framing and sheathing, stairs, cracked wall
0203	Insulation and moisture protection
0204	Masonry
0205	Exterior siding, incl. skirting
0206	Exterior doors and frames, incl. hardware and weatherstripping
0207	Storm and screen doors
0208	Window and frames, incl. hardware and weatherstripping
0209	Storm windows and screens
0210	Exterior trim
0211	Porch/deck construction
0212	Interior drywall, incl. fasteners and accessories
0213	Wall coverings and paneling
0214	Interior doors, frames, and hardware, incl. bifold and sliding
0215	Interior casework and finish carpentry
0216	Bathroom accessories, mirror
0217	Kitchen accessories, cabinets
0218	Drapery hardware
0219	Other exterior/interior repair, venetian blinds
0220	Garage door

### 03 Floor Coverings

0301	Resilient flooring
0302	Carpet and pad
0303	Ceramic flooring
0304	Underlayment/substrate
0305	Other flooring repairs

### 04 Interior Painting

0401	Walls and ceilings, incl. patching
0402	Trim
0403	Touch-up
0404	Bathtub/shower unit caulking
0405	Other Interior painting

## 05 Exterior Painting

- 0501 Walls, siding, incl. skirting
- 0502 Doors, frames, trim
- 0503 Exterior trim, incl. window, fascia, rake, soffit, etc.
- 0504 Caulking and sealing
- 0505 Glazing
- 0506 Other exterior painting

## 06 Heating

- 0601 Heating plant, valve
- 0602 Motors, blowers, pumps, G-60
- 0603 Ducts
- 0604 Piping
- 0605 Diffusers, grills
- 0606 Insulation
- 0607 Heating controls
- 0608 Other heating repairs, instructions for thermostat, turn on gas

## 07 Air Conditioning

- 0701 Cooling coils, compressor, condenser, valve, contactor
- 0702 Motors, blowers, pumps, transformer, fuses
- 0703 Piping, ducting
- 0704 Refrigerant
- 0705 Insulation
- 0706 Controls, delay module, relay
- 0707 Other cooling repairs, instruct thermostat use, filter

## 08 Plumbing

- 0801 Water heater
- 0802 Water softener
- 0803 Piping, supply, incl. valves, arrestors
- 0804 Faucets and shower heads
- 0805 Lavatories, incl. support and fasteners, caulking
- 0806 Water closets (i.e., toilets and commodes), incl. support and seals, caulking
- 0807 Bathtub/shower unit
- 0809 Other plumbing repair

## 09 Electrical

- 0901 Service entrance
- 0902 Panel box, incl. circuit breakers
- 0903 Branch circuits, incl. junctions, fasteners
- 0904 Wall receptacles and switches

0905	Doorbells, chimes
0906	Light fixtures
0907	Vents, fans
0908	Other electrical repair

## **10 Equipment**

1001	Disposal
1002	Dishwasher
1003	Stove, range
1004	Range hood
1005	Refrigerator
1006	Other equipment

## **11 Utility Plant Equipment**

Not applicable

## **12 Utility Service**

1201	Water supply
1202	Gas supply
1203	Electrical service
1204	Sanitary/sewer
1205	Other utility service

## **13 Miscellaneous**

## APPENDIX D: ENERGY EFFICIENCY TESTS OF 15 CONVENTIONALLY BUILT HOUSING UNITS

The objective of these tests was to provide data concerning the energy efficiency of conventionally built housing. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

### I. Tests Performed Upon Completion of Construction

Tests were conducted over 4 days in June 1983 on three types of buildings: a fourplex, a fiveplex, and a sixplex. Weather conditions were typical of the high desert area: light to negligible winds, clear skies, low humidity, and temperatures ranging from lows near 70 °F to highs near 110 °F.

#### House Tightness

A blower door apparatus was used to measure each unit's tightness. The blower door consisted of a variable speed fan, a digital tachometer to measure the fan blade rotation speed, and an inclined manometer to measure pressure differences. The fan could be operated to induce a positive or negative pressure difference in the house with respect to the outdoors.

To perform this test, the fan was fitted tightly into an outside door frame. A barbed fitting which penetrates the blower door was fitted with rubber tubing and connected to one side of the manometer. The other side of the manometer was open to the house. When the fan was operated, it could either force air into the house (pressurized) or force air out of the house (depressurized) depending on the direction of rotation. In either case, the pressure difference between the house and the outdoors could be read on the manometer. The fan speed was adjusted until a specified pressure difference existed (usually 0.1 or 0.2 in. of water). The fan speed required to achieve a given pressure was correlated to air flow, which indicated how tightly the house was sealed.

Each of the units was tested at 0.1 and 0.2 in. H<sub>2</sub>O pressurized, and 0.2 in. H<sub>2</sub>O depressurized. Some of the more obvious leaks (furnace room doors, dryer vents, attic doors) were then taped, and the house was again tested at 0.2 in. H<sub>2</sub>O depressurized.

As shown in Table D1, airtightness was adequate, requiring no corrective work.

#### Furnace Efficiency

The furnaces in all the units were propane-fired. Tests were performed with a Fuel Efficiency Monitor (FEM), a hand-held automatic flue gas analyzer which measures the flue gas temperature, oxygen content, and ambient conditions and uses this information to calculate and display the percent efficiency of the furnace.

Each housing unit was first cooled down to allow the furnace to operate. The thermostats in the houses were of the "energy-saving" type, and included night setback and temperature limits. These were disconnected before each test so that the heating and air conditioning could be manually adjusted. The safety relief on the front of each furnace was covered so that room air would not be introduced into the flue. The furnace was then turned on, and a sample was taken of the intake air using the FEM. A 1/8-in.

Table D1

## CBU Energy Efficiency Data After Construction

Building/Unit	UA* Btu/Hr-°F	No. Air Changes** Per Hour	Furnace*** Efficiency (%)
3720A	213	11.4	52.6
3720B	181	12.1	61.3
3720C	181	13.1	62.8
3720D	213	12.8	67.2
3720E	304	12.4	71.7
3720F	304	13.2	73.0
3724A	181	11.8	61.9
3724B	181	13.3	62.6
3724C	304	13.0	71.4
3724D	304	15.1	72.3
3725A	181	11.7	61.6
3725B	181	12.8	****
3725C	213	13.9	69.3
3725D	304	13.4	72.7
3725E	304	14.8	****

\*These are calculated values based on the wall construction. U=heat transfer; A = area

\*\*The following rating of air changes per hour at 0.2in. water column is based on work currently being done by Mansville Corp. for the U.S. Navy; 0 to 5, objectively tight; 5 to 10, excellent; 10 to 15, satisfactory; 15 and above merits corrective work.

\*\*\*Most gas fired furnace manufacturers claim 80 percent efficiency.

\*\*\*\*Unable to test furnace due to lack of access to the units.

hole was then drilled in the flue of the furnace. After allowing a few minutes for the furnace to reach steady state, the FEM probe was inserted into the flue pipe and a sample was taken of the exhaust gas. The FEM took 2 to 3 min to calculate the furnace efficiency.

Table D1 shows the furnaces' operational efficiencies.

### Wall Heat Transfer Characteristics

A Thermo Flow Energy Meter (TEM) was obtained to test the heat transfer characteristics of the walls. The TEM is an infrared radiometer which displays heat flow digitally in units of Btu/hr/sq ft. It can be used to detect insulation defects and to estimate the thermal resistance of exterior walls.

Due to unfavorable weather, the TEM could not be used to calculate R-values. The device was also useful for detecting insulation voids. No insulation voids were found.

## II. Tests Performed after Five Years' Occupancy

The house tightness and furnace efficiency tests were performed again in May 1988. Results are summarized below in Table D2.

Again, no wall insulation tests were performed because of weather conditions.

Table D2  
CBU Energy Efficiency Data 5 Years After Construction

Unit No.	No. Air Changes Per Hour	Furnace Efficiency (%)
3720A	11.0	58.5
3720B	11.4	68.6
3720C	12.9	65.8
3720D	10.2	70.6
3720E	10.6	74.2
3720F	10.8	59.5
3724A	10.6	68.9
3724B	11.6	57.8
3724C	14.4	67.4
3724D	12.3	70.4
3725A	11.3	66.0
3725B	11.8	24.1
3725C	14.4	68.8
3725D	16.2	67.3
3725E	12.4	74.5

## APPENDIX E: ENERGY EFFICIENCY TESTS OF 16 MANUFACTURED HOUSING UNITS

The objective of these tests was to provide data on the energy efficiency of manufactured housing units which will be compared to existing energy efficiency data taken on conventionally built housing units. Tests were performed to determine the airtightness of the units (a measure of the resistance to air infiltration), furnace efficiencies, and heat transfer characteristics of the building envelope.

### I. Tests Performed Upon Completion of Construction

Tests were conducted on three types of fourplexes; Type I (Building 3809), II (Building 3802), and IV (Buildings 3800 and 3806). The tests were conducted over 4 days in April 1984. The weather during the testing was mild for high desert area; medium to strong winds, overcast skies, low humidity, and temperatures ranging from morning lows of 40 °F to highs near 80 °F.

#### House Tightness

To measure the tightness of each housing unit a blower door apparatus was used, as described in Appendix D.

Each of the manufactured housing units was tested at 0.1, 0.2, and 0.3 in. of water during pressurization and then tested at 0.1 and 0.2 in. under depressurization. Then air leaks were taped (furnace doors and kitchen vents) and the unit was retested at 0.2 in. during pressurization. During the final day the winds were gusting so high that no consistent manometer reading could be taken, so Building 3809 had no data for air infiltration.

The results of the USACERL testing, as presented in Table E1, demonstrate that the airtightness of all the units except one is acceptable. Unit 3800-C had a significantly higher value than the other units and should have corrective work done to improve its tightness.

During the airtightness testing, several leaks were found. In Type II, Unit 3802-C, serious leaks were found in the door to the furnace room. In Type IV, Units 3800 and 3806, leaks were found while depressurizing around the furnace vents and doors (Unit A in both buildings). Also, leaks were found around sliding doors (Unit 3800-C), kitchen window area (Unit 3806-D), utility outlets (Unit 3800-D), and a crack in the dining room wall (Unit 3806-D).

#### Furnace Efficiency

The furnaces in all of the units were propane-fired. Tests were performed using a FEM, as described in Appendix D. A carbon monoxide meter similar to the FEM was used to ensure that each furnace's burner was completely combusting its fuel and that there was no unusual concentration of carbon monoxide.

**Table E1**  
**MHU Energy Efficiency Data After Construction**

Building/Unit	UA* Btu/Hr-°F	No. Air Changes Per Hour	Furnace Efficiency (%)
3800A	296	9.9	75.5
3800B	296	11.5	81.8
3800C	363	18.4	80.5
3800D	363	11.3	82.6
3802A	271	9.0	70.1
3802B	271	10.1	75.1
3802C	370	12.1	81.8
3802D	370	11.3	80.3
3806A	296	8.0	78.2
3806B	296	9.8	77.4
3806C	363	8.7	80.7
3806D	363	10.6	82.2
3809A	249	**	80.0
3809B	249	**	82.0
3809C	336	**	80.7
3809D	336	**	79.6

\*These are calculated based on the wall construction. U = heat transfer coefficient; A = area.

\*\*Unable to test airtightness due to high winds.

The testing was performed in the early morning hours so there would be a low outdoor temperature to start the furnace. The safety relief on the front of each furnace was taped over to prevent room air from entering the flue. A 1/8-in. hole was drilled into the flue near the furnace. The furnace was turned on and a sample of the ambient air was taken. The furnace was then left to reach steady state (approximately 15 min) and then the FEM probe was inserted into the hole and a sample of the exhaust gas was taken. The FEM took approximately 2 to 3 min to calculate and display the efficiency. Three samples were taken to ensure furnace steady state. The hole in the flue was then taped closed.

The furnace efficiencies are typical for the size and type of furnace installed.

### Wall Heat Transfer Characteristics

A TEM, as described in Appendix D, was used to test the heat transfer characteristics of the exterior walls of each unit and to detect insulation defects.

This testing was done in the early morning hours because there must be a constant temperature difference of at least 20 °F between outdoor and indoor temperatures. First the outdoor and indoor temperatures were taken until they appeared steady; next the TEM was aimed at an interior wall and the net heat flow reading was recorded. Then the TEM was aimed at an exterior wall and the heat flow through the wall was recorded. Finally the same measurement was made on the outside of the exterior wall (being sure that the area was shaded from sunlight). These results were used in conjunction with a standardized chart to determine the wall's thermal resistance. After these measurements were taken, the TEM was used to detect areas of high net flow readings, which indicate areas of insulation defects. There appear to be a number of insulation voids in Type I, II, and IV Units.

The UA values were calculated for the units, representing the overall heat transfer for the unit inclusive of walls, windows, doors, and roof (heat transferred from one unit to the next unit was considered negligible). The insulation voids listed in Table E2 were determined when the net heat flow varied by 10 Btu/hr-°F.

## II. Tests Performed After Five Years' Occupancy

The house tightness and furnace efficiency tests were performed again 5 years after construction. Results are given in Table E3.

Table E2  
Insulation Void Locations

Building/Unit	Location of Void
3802A	Void area at upper left corner of window in front bedroom.
3802C	Void area above sliding glass door in dining room.
3802D	Void area at right electrical outlet in dining room.
3806C	Void areas in all wall-to-wall seams (corners).
3806D	Void areas in all wall-to-wall seams (corners).
3809B	Void area at upper right corner of sliding glass door in dining room.

Table E3

MHU Energy Data 5 Years After Construction

Building/Unit	No. Air Changes Per Hour	Furnace Efficiency (%)
3800A	7.8	75.9
3800B	9.4	80.2
380c0	*	76.3
3800D	10.2	72.8
3802A	9.6	71.2
3802B	10.2	80.4
3802C	10.8	79.1
3802D	*	*
3806A	8.6	79.9
3806B	10.3	77.1
3806C	11.4	79.8
3806D	12.9	76.6
3809A	7.4	78.7
3809B	7.0	73.9
3809C	10.2	79.2
3809D	10.3	78.3

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