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SHOWER TESTING FOR THE TEXAS DEPARTMENT OF CORRECTIONS

Volume 1

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EXECUTIVE SUMMARY

Measurements have been conducted on four low flow showerheads highly recommended by utilities. These measurements were made to determine expected cost savings in TDC installations, based on water savings, sewer savings, and energy savings. Flow rates of 1.95 gpm at 40 psi were found for three of the showerheads tested. This compares with the 2.5 gpm rating of the standard heads used by TDC. Hence, any of these three heads tested would provide total annual savings of $12,337 at Gatesville and $11,036 at Amarillo, or over $35 per showerhead compared with the showerheads currently being used by TDC. The estimated payback is less than two months.

The savings determined are about one-third the estimate made before testing, since the low flow heads tested require that supply water temperatures be approximately 10 F higher than standard heads to achieve comparable temperatures in the spray pattern, and further study has shown lower shower water usage than initially estimated. Over 80% of the savings projected will be due to reduced water and sewer costs. Further testing to determine whether very low flow heads exist which do not require elevated supply temperatures are recommended.

It is also recommended that further testing be conducted to determine if the 105 F now used to supply TDC showers is optimal. Limited comfort testing suggests that supply temperatures closer to 100 F may be appropriate.

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SHOWER TESTING

INTRODUCTION

The design review of the TDC facilities planned for Amarillo and Gatesville (1) identified reduced flow showerheads as a measure which had the potential for saving over $70,000/year with an estimated initial investment of less than $7,000. This project was intended to measure the flow rate of several low-flow showerheads which have been reported to provide acceptable shower quality and verify the energy savings of the showerheads. Subsequently, four models of water-conserving shower heads were obtained and tested.

The measurements showed that the showerheads operated at lower flow rates than standard showers but subjective impressions from use of the showerheads suggested that inlet water temperature had to be raised to obtain an equal level of comfort with the lower flow showerheads. Simple calculations showed that this phenomenon had the potential to reduce the expected energy savings substantially for typical operation in Texas.

This has significant implications for all state-owned facilities in Texas which use large amounts of hot water for showers.

TESTS CONDUCTED

Showerheads Tested

The American Council for an Energy Efficient Economy was contacted for information on low-flow showerheads which had been found to provide satisfacyntory showers. They recommended contacting two utilities (PSEG of New Jersey and Northeast Utilities, Connecticut) which have conducted extensive shower testing. The utilities have not released results of their testing, but supplied the names of three manufacturers which had supplied showerheads for their programs. The utilities reported they had been highly satisfied with customer response to showerheads from these manufacturers. The following showerheads were obtained and tested:

Niagara Model #N2130 denoted #1

Wheedon Model #SN1B denoted #2

G&E Products #GE-B1 denoted #3C, #3F

Niagara Model #N2120 denoted #4, #5

Two heads of model #N2120 were tested as a check on the repeatability of the measurements. All except G&E Products #GE-B1 are aerating type heads. #GE-B1 is an adjustable head with a simple plastic adjusting ring. It provides a useful basis for comparison since it is not an aerating head, but would not be suitable for TDC use, since the adjusting ring is completely removable from the head. This head was tested at the limits of its course/fine spray adjustment, with the head labeled as #3C when on the course setting and #3F when on the fine setting.

Test Setup

A standard three-foot square shower stall was set up at the Energy Systems Laboratory with the showerhead position at a height of 72-inches. The cold and hot water were mixed using two ball valves and the mixed water line was instrumented to measure the pressure, flow rate and temperature of the water entering the showerhead as shown in Figure 1.

Six temperature measurements were normally taken as shown in Figure 2. The dry-bulb and wet-bulb temperatures (T_{room}, T_{wb}) of the laboratory just outside the shower stall were recorded. The entering water temperature, T_{water}, was taken in the water line near the showerhead. Three measurements were made near the center of the shower spray pattern at distances of one foot (T_1), two feet (T_2), and three feet (T_3) from the showerhead, respectively. All measurements except T_{wb} were made with Type T (copper constantan) thermocouples. T_{wb} was measured with a mechanically aspirated mercury thermometer enclosed in a standard wick.

Measurements were made at additional positions during some of the preliminary measurements, but were not used in the final analysis since they had minimal value in assessing differences between the different showerheads. These measurements included one outside the spray pattern, but inside the shower stall. This measurement was typically higher than ambient when the shower was running but significantly cooler than those taken within the water pattern. Other measurements were taken one-, two-, and three-feet from the showerhead along a line near the edge of the shower spray pattern.

A limited number of tests were also conducted where people entered the shower stall and the temperature was adjusted until comfort was achieved. One head provided shower comfort with inlet water temperatures 4-10 F lower than the other showerheads.

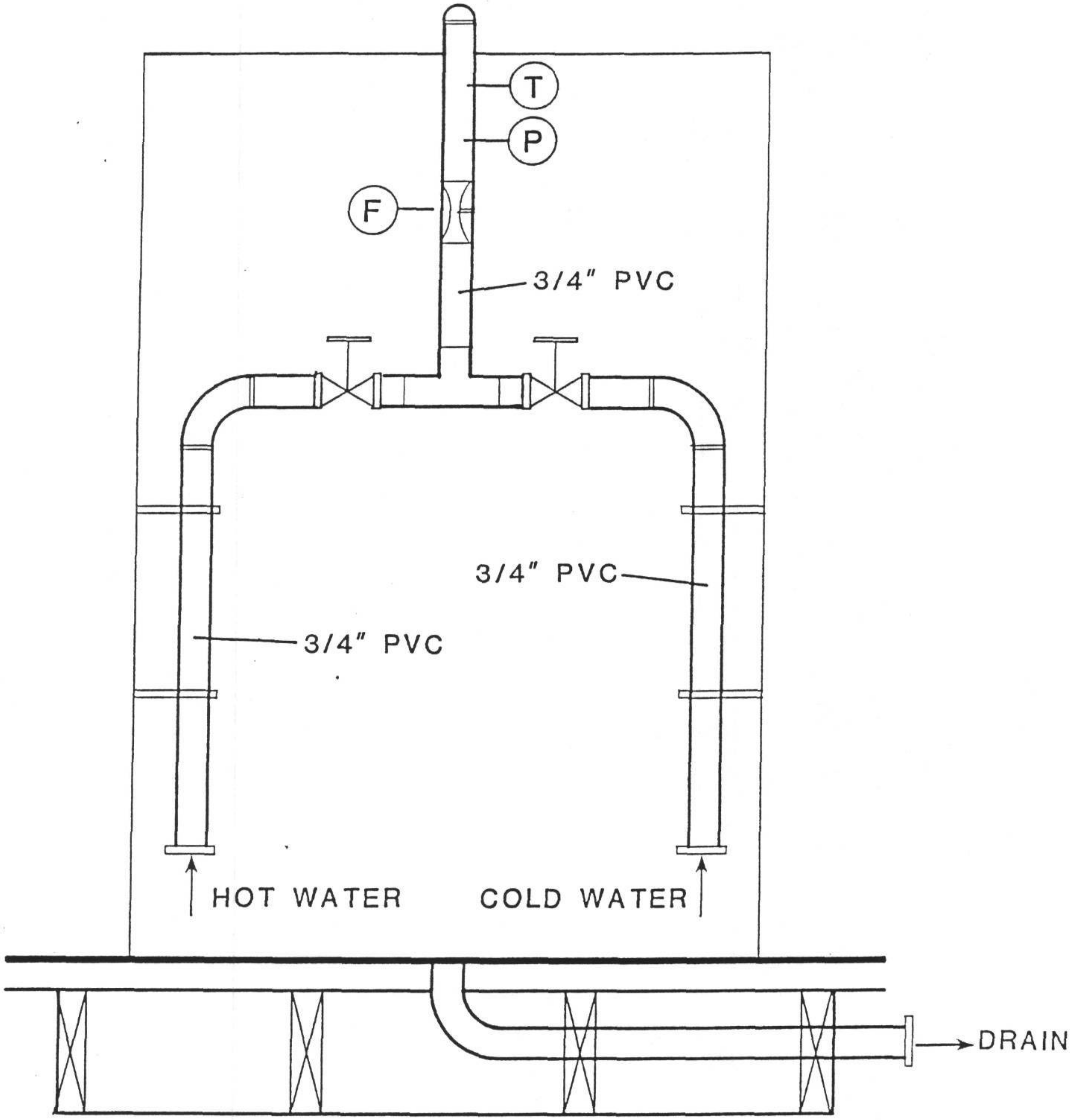

Figure 1. Schematic drawing of shower showing positions of valves, rotameter (F), pressure tap (P), and mixed water temperature thermocouple (T).

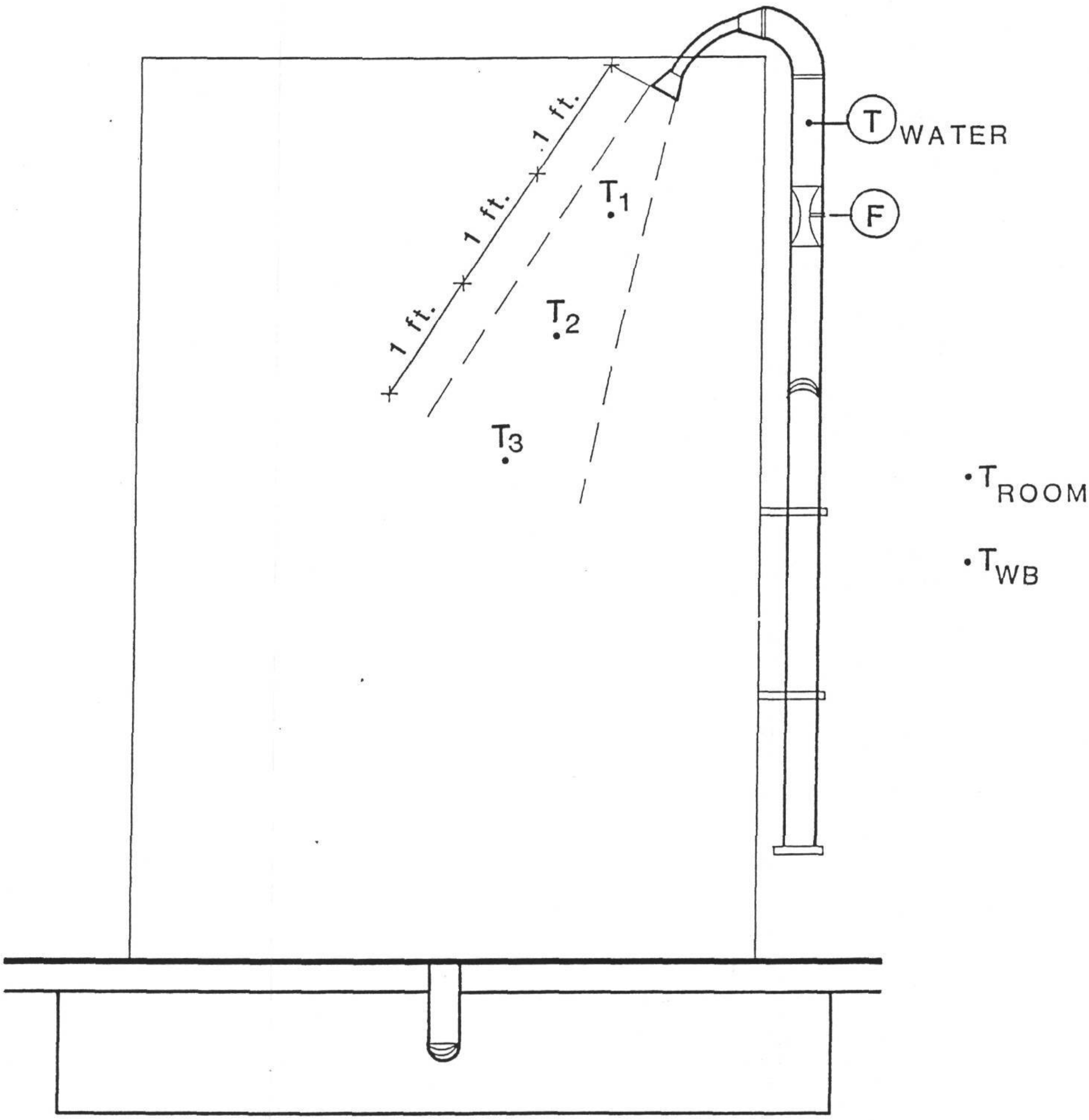

Figure 2. Schematic drawing showing positions of six key temperature measurement positions.

TEST RESULTS

Flow-Rate Testing

The flow rate of the showers was measured, typically near 40 psig. Results at 40 psig for the showerheads tested were as follows:

Head #	Flow @ 40 psig (gpm)	Rated Flow @ 40psig (gpm)
1	1.95(1.9-2.1)	1.81
2	1.97(1.9-2.0)	2.0
3	2.1 (1.9-2.2)	2.75 (any psi)
4	1.9 (1.9-1.9)	1.81
5	1.95(1.9-2.0)	1.81

The measured flow values shown are the average of multiple measurements with the range of measured values shown in parentheses. Since heads #4 and #5 were two samples of the same model and #1 had the same rated flow, we conclude that there were not significant differences in flow among the three aerating heads tested. Hence, a value of 1.95 gpm will be used for comparison with the rated flow of 2.5 gpm @ 40 psig for the Bradley Built-in Shower Models 9062/9051 currently used in TDC facilities.

Initial tests were conducted during the summer when interior temperatures at the ESL were typically in the 90-95 F range and "cold" water temperatures were comparable. Tests were conducted at several water temperatures, but the most informative were those made using "cold" water. Results of these tests are summarized in Table 1.

Table 1

Results of Initial Showerhead Testing

Measurement #	T_{room}	T_{water}	T_{shower}	T_{stall}
1	90.4	92.8	91.3	84.8
2	90.3	92.7	91.2	84.6
3	89.7	92.5	91.2	85.4
4	89.7	92.7	91.3	84.9
5	89.8	92.8	91.2	85.6
6	90.2	92.8	91.4	85.8
7	90.6	92.9	91.2	85.2
8	91.0	92.9	90.9	85.1
9	90.9	92.8	90.7	85.0
Average	90.3	92.8	91.2	85.2

The water enters the showerhead at T_{water}, reaches the temperature T_{shower} near the head in the spray pattern and drops to T_{stall} in the shower stall, but outside the main spray pattern, while the temperature of the lab was T_{room}. The most striking result shown in the table is that the temperature T_{stall} is 5.1 F below the room temperature and 7.6 F lower than the temperature at which the water was supplied to the shower! This is a result of evaporative cooling by the aerating shower nozzles. The amount of evaporative cooling which occurs depends on the nozzle design, the water supply temperature, and the wet-bulb temperature.

Subsequently, 14-28 measurements were made on each showerhead using a variety of water temperatures and room temperatures. Temperatures were measured at five locations as noted in Figures 1 and 2. Results of these measurements are provided in Appendix C and are summarized in Appendix A.

The non-aerating head #3C consistently produced higher temperatures within the spray pattern for a given supply temperature, T_{water}. Consequently, head #3C has been used as a base case for the comparison presented in Table 2. The water temperature which must be supplied to the other heads to approximate the temperatures in the spray pattern of #3C when supplied at 105 F is given in the Table. Note that 105 F is the supply temperature at TDC units.

Due to variation in the results measured for different heads at different positions within the spray pattern and to changes in laboratory conditions, a procedure was developed to normalize and compare data taken at a variety of "hot" water temperatures and "room" temperatures. This procedure is described in Appendix A. Using these procedures, Table 2 shows the water temperature required by the aerating heads to produce the same temperatures at distances of one-, two- and three-feet from the head as those produced by head #3C when it is supplied with 105 F water. The average value of the temperatures required at these distances is shown in the column labeled "Avg." and the increase in temperature required compared to #3C is shown in the column labeled "Diff."

Table 2

Water Temperatures Required by each Head to Produce Temperatures of 101.2 F, 95.9 F and 95.3 F at Distances of One, Two and Three Feet from the Head.

Head	One Ft.	Two Ft.	Three Ft.	Avg.	Diff.
#1	114.6	115.8	130.1	120.2	15.2
#2	110.3	106.9	109.3	108.8	3.8
#3	105	105	105	105	0.0
#4	113.3	114.3	120.6	116.1	11.1
#5	111.4	116.4	120.2	116.0	11.0

These results show that the aerating heads require water 2.8 - 10.9 F warmer on average to provide the same temperatures within the spray pattern as the non-aerating head #3C and suggest that #2 would be the preferred aerating head.

HUMAN COMFORT TESTING

The showers were then tested by four people under the same controlled conditions. Each person entered the shower, the water was adjusted until it was too cool for comfort, and was then readjusted until it was considered "comfortable:. The temperature of the water entering the shower head was then recorded. Each person's "comfort temperature" was determined twice for each showerhead with a 5-10 minute period between the two determinations. The results are shown in Table 3. Note that #4 was omitted from this test since the earlier results showed it to perform in an essentially identical manner as expected.

It can be seen that #3C requires the lowest water temperature, as expected, based on the results of Table 2. The average temperature required by the four testers was 98.375 F. The aerating showerheads required temperatures 4.1-10.2 F higher. However, this time, #1 showed the smallest increase in required temperature. Note that head #3 was also tested adjusted to its finest spray position (#3F) and also required a higher supply temperature than when adjusted to its coarse position (#3C).

Table 3

"Comfort Temperatures" Determined by Four Testers for Different Showerheads

Head	Tester #1	Tester #2	Tester #3	Tester #4	Average
#1	108.5	103	93	105.5	102.5
#2	115.5	109	103	107	108.6
#3C	99	100	94.5	100	98.4
#3F	105	101.5	94.5	103.5	101.1
#5	115.5	106.5	103	108	108.2

SAVINGS ESTIMATES FOR LOW-FLOW SHOWERHEADS

The three low-flow aerating showerheads tested appeared to be nearly identical in design and construction. The testing reported in the previous section showed that they consistently required higher supply temperatures than the non-aerating head to produce the same level of temperature and/or comfort in the spray pattern. All three aerating heads produced a flow rate of 1.95 gpm @40 psig within experimental error and the discrepancies between results of the temperature measurements and the comfort measurements suggest that all three will have equivalent operating temperatures.

The testing indicates that the aerating heads can be expected to require water at approximately 115 F to achieve the same spray temperature as that provided by non-aerating heads with 105 F water. The additional energy required to heat the water to 115 F will reduce the gas savings substantially, but the aerating heads still produce net savings of $ 11,036/yr in Amarillo and $12,337 in Gatesville, based primarily on the water cost savings.

Table 4

Annual Cost Savings Estimates for Aerating Low-Flow Showerheads in TDC Facilities in Amarillo and Gatesville

Location	Water & Sewer Savings	Gas Savings	Total Savings
Amarillo	$ 9,489	$ 1,547	$ 11,036
Gatesville	$ 11,675	$ 662	$ 12,337

Each facility has 302 showerheads, so the annual savings per showerhead is still $36 - $41 per showerhead. The aerating heads themselves sell for less than $4 per head in quantity, but the heads must be factory assembled onto the built-in shower assemblies used by TDC, so the cost will have to be negotiated with the manufacturers. However, based on the price of the aerating heads, the payback should be two months or less.

CONCLUSIONS

The measurements conducted have shown flow rates of 1.95 gpm at 40 psi for the showerheads tested. Hence, the Niagara Model #N2120, Niagara Model #N2130 and the Wheedon Model #SN1B would all result in water savings of approximately 22% compared with the Bradley Built-in Shower Models 9062/9051 currently used by TDC. However, energy savings would be only 2.4% in Gatesville and 6.0% in Amarillo if the same comfort levels are achieved since the circulating water temperature would need to be raised approximately 10 F to achieve the same water temperatures in the shower stall.

While the total cost savings have been reduced by a factor of three from the original estimate, the payback will still be approximately 1-2 months, depending on the price which can be negotiated with suppliers.

It is recommended that further testing be conducted to determine if the 105 F now used to supply TDC showers is optimal. Our comfort results, based on a very small sample, suggest that supply temperatures closer to 100 F may be appropriate. It is further suggested that further testing be conducted on a wide range of showerheads to establish relevant characteristics for purchase and use in state facilities. It seems probable that models can be located which provide low flow rates while minimizing evaporative cooling.

APPENDIX A

The results given in Appendix B are summarized and normalized in this appendix. The results in Table A.1 are normalized for readings taken at different temperatures so that a value of zero would correspond to the measured temperature at the points one-, two- or three-feet from the shower head being the same as the temperature of the water entering the head, while a value of "1.0" would correspond to the measured value being the same as the room temperature. It can be seen that the aerating heads (#1, #2, #4 and #5) always show a larger drop in temperature from T_{water} to T_1, T_2 and T_3 than is true for the non-aerating head in its course setting, #3C.

Table A.1

Summary of Normalized Temperature Drop in Spray Pattern for Five Showerheads Tested

Head		Position	
	One Foot	Two Feet	Three Feet
#1	0.301	0.435	0.579
#2	0.225	0.298	0.356
#3C	0.108	0.260	0.277
#3F	0.143	0.425	0.405
#4	0.280	0.416	0.500
#5	0.246	0.442	0.496

The normalized temperature drop T_n corresponds to

$$T_n = (T_{water} - T_i)/(T_{water} - T_{room})$$

for the values i = 1,2,3. Table 2 shows that the temperature in the spray pattern drops appreciably less for head #3C than for the other heads. This is illustrated in Table A.2 which presents the temperature at these points in the spray pattern if the measurements had been made with T_{water} of 100 F and T_{room} of 70 F.

Table A.2

Expected Temperature at Three Points in the Spray Pattern for the Heads Tested when T_{water} = 100 F and T_{room} = 70 F

Head	Position One Foot	Two Feet	Three Feet
#1	90.97	86.95	82.90
#2	93.25	91.06	89.32
#3C	96.76	92.20	91.69
#3F	95.71	87.25	87.85
#4	91.60	87.52	85.00
#5	92.62	86.74	85.12

As noted in the body of the report, it seems reasonable to assume that the best basis for comparing the showerheads would be to determine the temperature at which the water must enter to achieve specified temperatures at specific positions. Using head #3C as the base case, Table A.3 shows the water temperature required by the aerating heads to produce the same temperatures a distances of one-, two- and three-feet from the head as those produced by head #3C when it is supplied with 100 F water.

Table A.3

Water Temperatures Required by each Head to Produce Temperatures of 97.3 F, 93.5 F and 93.1 F at Distances of One, Two and Three Feet from the Head.

Head	One Foot	Two Feet	Three Feet	Average
#1	106.9	107.7	118.0	110.9
#2	103.8	101.4	103.1	102.8
#3C	100.0	100.0	100.0	100.0
#4	106.0	106.7	111.2	108.0
#5	104.6	108.2	110.9	107.9

This corresponds closely to the water temperature determined to be most comfortable for #3C in the comfort testing conducted.

APPENDIX B

SAVINGS ESTIMATES FOR LOW-FLOW SHOWERHEADS

The three low-flow aerating showerheads tested appeared to be nearly identical in design and construction. The testing reported in the previous section showed that they consistently required higher supply temperatures than the non-aerating head to produce the same level of temperature and/or comfort in the spray pattern. All three aerating heads produced a flow rate of 1.95 gpm @40 psig within experimental error and the discrepancies between results of the temperature measurements and the comfort measurements suggest that all three will have equivalent operating temperatures.

Water savings are estimated based on comparison of 1.95 gpm for the low-flow heads compared with the present value of 2.5 gpm. TDC personnel have inmate showers and report an average shower length of 10 minutes (B-1). It is estimated that each inmate takes an average of 1.1 showers per day (B-2). Hence the potential water savings are estimated to be:

$$(1.1 \times 10)\ \frac{\text{shower-minutes}}{\text{inmate-day}} \times (2.50-1.95)\ \text{gpm} \times 2250\ \text{inmates} \times 365\ \text{days/yr} = 4{,}968{,}000\ \text{gallons/year}$$

at each facility Water costs $0.91/1000 gallons at Amarillo with sewage treatment cost estimated to be $1.00/1000 gallons (B-3) resulting in savings of $9,489/year from reduced water usage. At Gatesville, water costs $1.45/1000 gallons plus $0.90/1000 gallons for sewage, resulting in cost savings of $11,675 per year.

TOTAL SAVINGS: AMARILLO

Gas cost = $ 2.21/million Btu
Assume 75% heating efficiency
Average supply water temperature = 56.5 F

Present heads heat water from 56.5 to 105 F requiring

$$(105-56.5)\text{F} \times 8.3\ \text{lb/gal} \times 1\ \text{Btu/lb-F}/0.75 = 537\ \text{Btu/gal}$$

Gas for heating water is

$$75 \times 2250 \times 365 \times 537 = 1.21 \times 10^{10}\ \text{Btu/yr}$$

$$\$2.21/10^{6}\ \text{Btu} \times 3.31 \times 10^{10}\text{Btu} = \$73151/\text{yr}\ @\ 2.5\ \text{gpm}$$

Aerating Heads will require: (assuming 115F supply temperature)

$$(115-56.5) \times 8.3 \times 1/0.75 = 647\ \text{Btu/gal}$$

$$75 \times (1.95/2.5)\ \text{gal/inmate-day} \times 2250 \times 365 \times 647 = 3.11 \times 10^{10}\ \text{Btu}$$

$1.14 \times 10^{10} \times \$2.21/10^6 = \$25,194/yr$

Gas cost savings are: \$26,741 - \$25,194 = \$ 1,547/yr
Water and sewage cost savings are 9,489

Total Savings - Amarillo \$ 11,036/Yr

TOTAL SAVINGS: GATESVILLE

Gas cost = \$ 3.15/million Btu
Assume 75% heating efficiency
Average supply water temperature = 66.0 F

Present heads heat water from 66.0 to 105 F requiring

(105-66.0)F x 8.3 lb/gal x 1 Btu/lb-F/0.75 = 432 Btu/gal

Gas for heating water is

$1.1 \times 10 \times 2.5 \times 2250 \times 365 \times 432 = 9.76 \times 10^9$ Btu/yr

$\$ 3.15/10^6$ Btu x 9.76×10^9 Btu = \$30,744/yr @ 2.5 gpm

Aerating Heads will require: (assuming a 115F supply temperature)

(115-66.0)x8.3x1/0.75 = 542 Btu/gal

$1.1 \times 10 \times 1.95$ gal/inmate-day $\times 2250 \times 365 \times 542 = 9.55 \times 10^9$ Btu

$9.55 \times 10^9 \times \$3.15/10^6 = \$30,082/yr$

Gas cost savings are: \$30,744 - \$30,082 = \$ 662/yr
Water and sewage cost savings are \$ 11,675/yr
Total Savings - Gatesville \$ 12,337/yr

References:

B-1: Communication from Robert E. Petty, May 1989.
B-2: Communication from Chet Buford, July 1989.
B-3: Communication from Chet Buford, July 1989.