CHAPTER

SIX

STATEWIDE ANALYSIS{ TC "STATEWIDE ANALYSIS" \l 1 }

The potential for UTC systems is calculated for several economic sectors in Wisconsin. Typical buildings are simulated in each sector, and the results are extrapolated to a statewide level.

6.1 Fuel and Equipment Costs{ TC "6.1 Fuel and Equipment Costs" \l 2 }

The fuel savings depends on the cost of the fuel being replaced. The average cost of fuel for the state of Wisconsin is given in Table 6.1.1 [Wisconsin Energy Bureau, 1995].

Table 6.1.1. Average cost of delivered energy in Wisconsin.**{** TC "Table 6.1.1. Average cost of delivered energy in Wisconsin." \l 7 **}**

Fuel Cost ($/mmBtu)		Commercial	Industrial	Residential
Natural Gas		4.55	3.17	6.20
Electricity		16.96	11.40	20.69
Distillate Oil		4.40	4.61	N/A
Fuel Oil		N/A	N/A	6.14
Fuel Cost ($/GJ)	**Efficiency**	**Commercial**	**Industrial**	**Residential**
Natural Gas	0.9	5.33	3.72	7.27
Electricity	1.0	17.89	12.03	21.83
Distillate Oil	0.9	5.16	5.40	N/A
Fuel Oil	0.9	N/A	N/A	7.20

Natural gas, distillate oil, and fuel oil are much cheaper than electricity. The values are in dollars per unit of heat supplied for the given efficiencies.

The first cost of a UTC system is affected primarily by the type of building on which the system is installed. The collector unit cost is approximately $40/m^2 for a new building installation and $80/m^2 for an existing building retrofit, for a collector area of over 500 m^2 uninterrupted by windows or doors [Hollick, 1995]. For smaller collectors, the first cost is $50/m^2 for a new building and $100/m^2 for an existing building [Hollick, 1995].

6.2 Commercial Sector{ TC "6.2 Commercial Sector" \l 2 }

Table 6.2.1 shows TRNSYS simulation results for typical commercial buildings in Wisconsin. These buildings are a health/education building, an office building, a retail building, and a warehouse. It is impossible to optimize the collector area (see Section 5.2) for every building in Wisconsin. Therefore, for this statewide analysis, the collector area is chosen such that the approach velocity at the building minimum required outdoor air flow is V = 0.035 m/s.

Table 6.2.1. Simulation results for typical commercial buildings in Wisconsin.**{** TC "Table 6.2.1. Simulation results for typical commercial buildings in Wisconsin." \l 7 **}**

Building	Q_{save}/A [GJ/yr-m^2]	T_{bal} [C]
A	1.42	13.1
B	1.45	15.0
C	1.53	19.5
D	1.57	19.0

The energy savings per unit area is dependent on the building balance temperature, as discussed in Section 2.5. As shown in Table 6.2.1, UTC systems on buildings with low balance temperatures save less energy than those on buildings with high balance temperatures. Although there is some variability in the energy savings in Table 6.2.1, there is not much because they all have the same approach velocity at the minimum outdoor air flow. In order to extrapolate the results from these simulations to a statewide basis, an average value of $Q_{save}/A = 1.5$ GJ/yr-m^2 is chosen.

There are several different market segments in the commercial sector. The total floor area in each segment has been estimated by the Wisconsin Center for Demand-Side Research [1995], as shown in Table 6.2.2. The units of KSF are 1000 ft^2.

Table 6.2.2. Commercial sector population estimates for Wisconsin.**{** TC "Table 6.2.2. Commercial sector population estimates for Wisconsin." \l 7 **}**

Market segment	Floor area [KSF]
Education	198,366
Grocery	26,888
Health	79,879
Lodging	39,899
Miscellaneous	217,164
Office	215,318
Restaurant	54,036
Retail	180,186
Warehouse	176,871

The outdoor air requirements for various commercial zones are compiled by ASHRAE [1989], as shown in plainface in Table 6.2.3. The average outdoor air requirement is estimated for each market segment (in boldface) from the ASHRAE values, except the grocery and warehouse values which are directly from ASHRAE. The outdoor air requirement of the miscellaneous segment is the average of the other segments.

Table 6.2.3. Outdoor air requirements for commercial buildings.**{** TC "Table 6.2.3. Outdoor air requirements for commercial buildings." \l 7 **}**

Market segment	Outdoor Air Requirement [m^3/s/KSF]
Education	**0.3**
Auditorium	1.062
Classroom	0.354
Corridor	0.047
Lab, shop	0.283
Library	0.142
Locker room	0.236
Grocery	**0.057**
Health	**0.14**
Med. proc./recovery/ICU/PT	0.142
Operating room	0.283
Patient room	0.118
Lodging	**0.2**
Assembly	0.850
Bathroom (ind. of size)	0.0165 [m^3/s/room]
Bed/living room (ind. of size)	0.0142 [m^3/s/room]
Conference	0.472
Dormitory sleeping	0.142
Lobbies	0.212
Miscellaneous	**0.24**
Office	**0.3**
Conference	0.472
Office space	0.066
Reception	0.425
Telecom/data entry	0.566
Restaurant	**0.8**
Bars, lounges	1.416
Cafeteria, fast food	0.944
Dining rooms	0.661
Kitchens	0.142
Retail	**0.1**
Basement, street level	0.142
Storage	0.071
Upper levels	0.094

Warehouse	**0.024**

The total collector area for a market segment is calculated for a UTC system installed on every commercial building to meet the outdoor air requirements in Table 6.2.3.

$$A_{seg} = \text{Floor Area} * \text{Outdoor Air Requirement} / V \qquad (6.2.2)$$

The number of segment stories is estimated using an estimated typical floor area for a single story.

$$N_{seg} = \text{Floor Area} / \text{Typical Single Story Floor Area} \qquad (6.2.3)$$

The total available south wall area is then estimated using Equation 6.2.4.

$$A_{avail,seg} = (\text{Typical Single Story Floor Area}*1000\ \text{ft}^2)^{0.5} * (12\ \text{ft}) * N_{seg} * (0.3048\ \text{m/ft})^2 \qquad (6.2.4)$$

The estimated south wall area calculation does not account for area unsuitable for a collector due to windows, doors, or shading. However, the south wall area is estimated only to determine whether the collector area calculated from Equation 6.2.2 is reasonable. A sample calculation is shown below for the education segment.

$$A_{seg} = (198{,}366\ \text{KSF})\ (0.3\ \text{m}^3\text{/s/KSF})\ /(0.035\ \text{m/s})$$

$$= 1{,}700{,}280\ \text{m}^2 \qquad (6.2.5)$$

$$N_{seg} = (198{,}366\ \text{KSF}) / (5\ \text{KSF})$$

$$= 39{,}673 \qquad (6.2.6)$$

$$A_{avail,seg} = (5*1000\ \text{ft}^2)^{0.5} * (12\ \text{ft}) * (39{,}673) * (0.3048\ \text{m/ft})^2$$

$$= 3{,}127{,}472\ \text{m}^2 \qquad (6.2.7)$$

There is enough available south wall area to accommodate the total collector area calculated in Equation 6.2.5 for the education segment. For every commercial market segment, the estimated available south wall area exceeds the total collector area, as shown in Table 2.6.4.

Table 6.2.4. Estimated south wall area for commercial buildings in Wisconsin.**{** TC "Table 6.2.4. Estimated south wall area for commercial buildings in Wisconsin." \l 7 **}**

Market segment	Typical Single Story Floor Area [KSF]	A_{avail} [m^2]	A [m^2]	A / A_{avail}
Education	5	3,127,472	1,700,280	0.54
Grocery	2	670,278	43,482	0.06
Health	8	995,632	319,516	0.32
Lodging	5	629,054	227,994	0.36
Miscellaneous	5	3,423,844	1,489,125	0.43
Office	5	3,394,740	1,845,583	0.54
Restaurant	2	1,347,037	1,235,109	0.92
Retail	5	2,840,843	514,847	0.18
Warehouse	10	1,971,822	119,262	0.06
Total		18,400,722	7,495,167	0.41

The collector areas from Table 6.2.4 are used to calculate the potential UTC system energy savings in a particular market segment.

$$Q_{save,seg} = (1.5 \text{ GJ/yr-m}^2) * A_{seg} \tag{6.2.8}$$

The fuel cost savings is calculated with the data from Table 6.1.1. In the commercial sector in Wisconsin, 69.4% of electric customers have access to natural gas [WCDSR, 1995]. It is assumed that all commercial buildings that have access to natural gas use it for space heating. The rest of the buildings use distillate oil for space heating. A negligible fraction of commercial buildings use electric heating [Wichert, 1995]. The potential fuel cost savings for the education segment is given by Equation 6.2.9.

$$FS_{seg} = Q_{save,seg} C_F \tag{6.2.9}$$

A sample calculation is shown for the education segment.

$$Q_{save,seg} = (1.5\ \text{GJ/yr-m}^2)\ (1{,}700{,}280\ \text{m}^2)$$

$$= 2{,}550{,}000\ \text{GJ/yr} \qquad (6.2.10)$$

$$FS_{seg} = (2{,}550{,}000\ \text{GJ/yr})\ [(\$5.33\ /\text{GJ})\ (0.694) + (\$5.16\ /\text{GJ})\ (0.306)]$$

$$= \$13{,}459{,}000\ /\text{yr} \qquad (6.2.11)$$

Equations 6.2.10-11 give the statewide technical potential of UTC systems in the education segment. The technical potential is the energy savings and fuel cost savings that result when all buildings use UTC systems, regardless of the economic feasibility of the system [WCDSR, 1995]. The technical potential for the commercial sector is given in Table 6.2.5.

Table 6.2.5. UTC system technical potential for commercial buildings in Wisconsin.**{** TC "Table 6.2.5. UTC system technical potential for commercial buildings in Wisconsin." \l 7 **}**

Market segment	Q_{save} [10^{12} J/yr]	FS [10^6 \$/yr]	FS [\$/ft^2-yr]
Education	2550	13.5	0.07
Grocery	65	0.3	0.01
Health	479	2.5	0.03
Lodging	342	1.8	0.05
Miscellaneous	2234	11.8	0.05
Office	2768	14.6	0.07
Restaurant	1853	9.8	0.18
Retail	772	4.1	0.02
Warehouse	179	0.9	0.01
All Segments	11,243	59.3	0.05

The fuel cost savings per unit floor area is also shown in Table 6.2.5. The typical annual fuel cost for space conditioning in Wisconsin is on the order of magnitude of \$1-2 /ft^2-yr [Mitchell, 1995].

The economic potential is the energy savings and fuel cost savings that result when UTC systems are only used by buildings on which they are economically feasible [WCDSR, 1995]. Obviously, the economic feasibility of a UTC system depends on its thermal performance. However, for a given thermal performance, there are two factors which affect the economics: the fuel and equipment costs, which are discussed in detail in Section 6.1. The life cycle savings is calculated for existing and new buildings with natural gas and electric heating. The price of distillate oil is slightly lower than that of natural gas, so the life cycle savings for buildings with distillate oil heating is slightly lower than that for buildings with natural gas heating.

The life cycle savings is calculated from Equation 5.1.1 using $Q_{save}/A = 1.5$ GJ/m^2 and $C_E = 0$. The worst economic case is an existing building (high first cost) with natural gas heating (low fuel savings). With natural gas heating, the life cycle savings never exceeds zero for a five-year period of economic analysis ($2.5 < P_1 < 5.0$), as shown in Figure 6.2.1. For a new building, the equipment costs are less than for an existing building, and the life cycle savings does exceed zero, as shown in Figure 6.2.2.

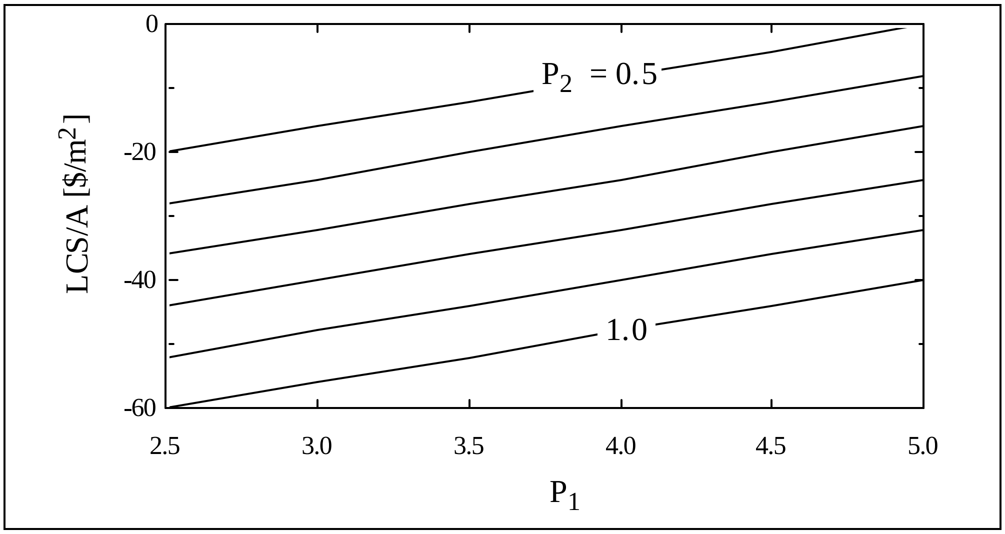

Figure 6.2.1. Life cycle savings for an existing building with gas heating.**{** TC "Figure 6.2.1. Life cycle savings for an existing building with gas heating." \l 5 **}**

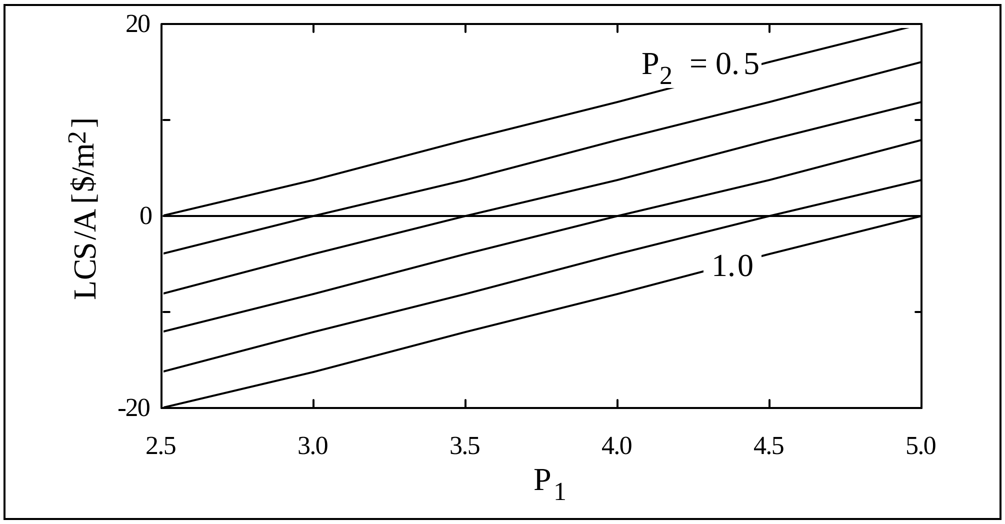

Figure 6.2.2. Life cycle savings for a new building with gas heating.**{** TC "Figure 6.2.2. Life cycle savings for a new building with gas heating." \l 5 **}**

A building with electric heating has a higher fuel cost savings than one with natural gas heating. Therefore, the life cycle savings is greater, as shown in Figures 6.2.3-4.

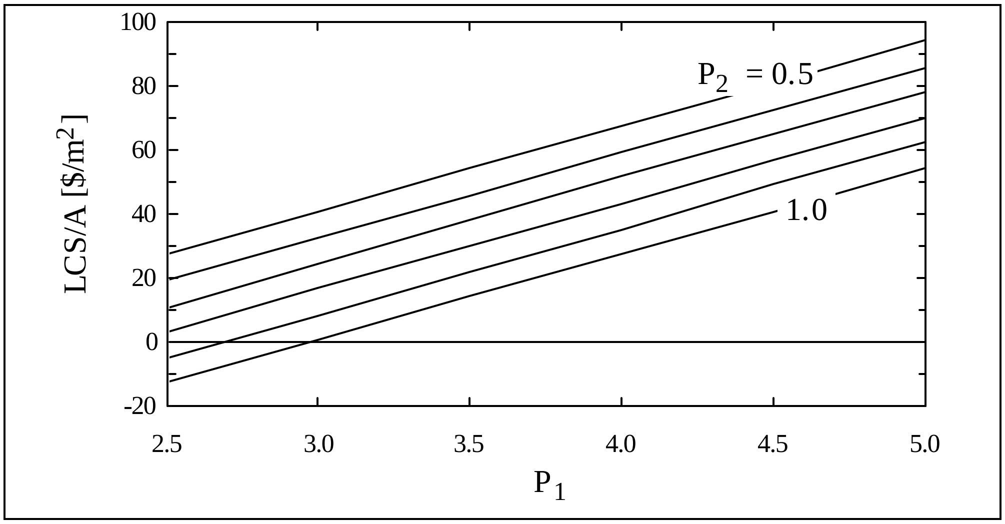

Figure 6.2.3. Life cycle savings for an existing building with electric heating.**{** TC "Figure 6.2.3. Life cycle savings for an existing building with electric heating." \l 5 **}**

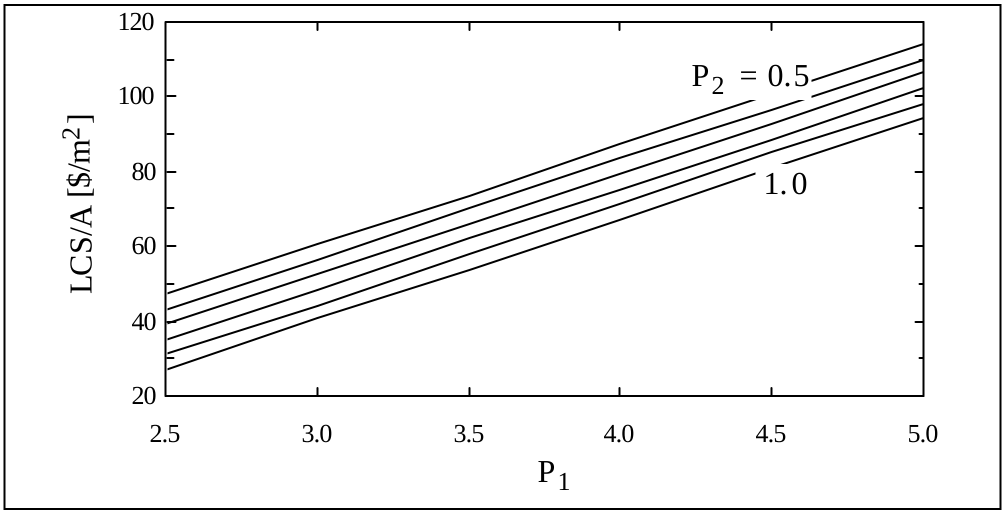

Figure 6.2.4. Life cycle savings for an new building with electric heating.{ TC "Figure 6.2.4. Life cycle savings for an new building with electric heating." \l 5 }

From Figures 6.2.1-4, the break-even line is at LCS = 0. P_1 and P_2 at the break-even condition are shown in Figure 6.2.5.

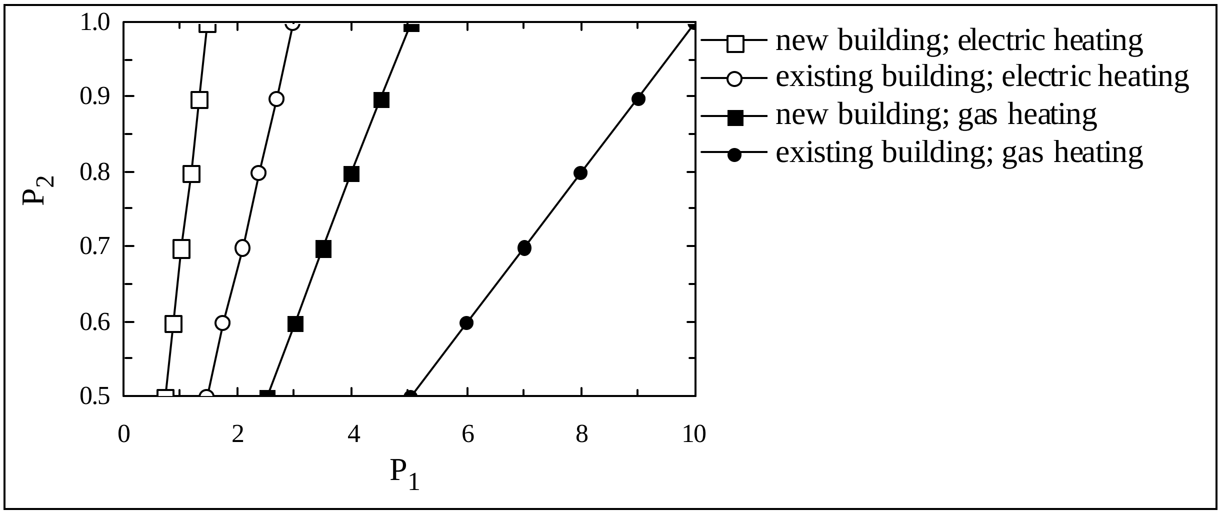

Figure 6.2.5. LCS = 0 curves for commercial sector.{ TC "Figure 6.2.5. LCS = 0 curves for commercial sector." \l 5 }

Figure 6.2.5 can be used to determine if a UTC system is a good investment for calculated values of P_1 and P_2. For example, estimating economic parameters may yield $P_1 = 5$ and $P_2 = 0.7$. This point lies to the left of the curve for an existing building with gas heating, which means that the life cycle savings will be negative. So a UTC system is a bad investment in this case. For the other three cases, a UTC system is a good investment.

However, only the ratio P_1/P_2 is needed to determine whether a UTC system is a good investment. The LCS = 0 lines in Figure 6.2.5 lie along constant ratios of P_1/P_2. This ratio is found from Equation 5.1.3.

$$P_1/P_2 = (C_E + C_A\ A) / (C_F\ Q_{save}) \qquad (6.2.12)$$

Using $C_E = 0$ and $Q_{save}/A = 1.5$ GJ/m^2, the ratio P_1/P_2 for LCS = 0 is shown in Table 6.2.6. For those readers not familiar with the P_1,P_2 method of life cycle savings, the minimum ratio P_1/P_2 from Equation 6.2.12 is also the simple payback period in years.

Table 6.2.6. Minimum P_1/P_2 ratios for positive LCS in the commercial sector.**{** TC "Table 6.2.6. Minimum P_1/P_2 ratios for positive LCS in the commercial sector." \l 7 **}**

Building, fuel type	C_A [\$/m^2]	C_F [\$/GJ]	P_1/P_2
New, electric	40	17.89	1.49
Existing, electric	80	17.89	2.98
New, gas	40	5.33	5.00
Existing, gas	80	5.33	10.01

For existing buildings, a UTC system is a good investment only if the building has electric heating. A negligible fraction of commercial buildings in Wisconsin use electric heating [Wichert, 1995]. Therefore, UTC systems do not have a significant statewide potential for use on existing buildings in the commercial sector. However, UTC systems should be considered for new commercial buildings in Wisconsin.

6.3 Residential Sector{ TC "6.3 Residential Sector" \l 2 }

The outdoor air requirement of a single-family dwelling is not large enough to operate a UTC system because the minimum approach velocity limits the collector to a small area. However, a multi-family dwelling may have a large enough outdoor air requirement for a UTC system. The outdoor air requirement for a residential building is 0.35 air changes per hour (ACH) but not below 15 cfm/person [ASHRAE, 1989]. A townhouse building in Madison, WI, that houses four families is chosen as a model. It is assumed that the average family size is three people, so twelve people live in the townhouses. The required 0.35 ACH yields an outdoor air flow below 15 cfm/person, so the outdoor air requirement for the townhouses is (15 cfm/person)(12 persons) = 180 cfm = 0.085 m^3/s. An approach velocity of 0.035 m/s is chosen, yielding a collector area of 2.4 m^2. The TRNSYS simulation shows that the UTC system energy savings is 1.56 GJ/m^2, which is in agreement with the results for commercial buildings (see Table 6.2.1). The collector area for the townhouses is too small to operate a UTC system with maximum efficiency, but a UTC system on a large apartment building would have a large collector area.

The life cycle savings is calculated from Equation 5.1.1 using $Q_{save}/A = 1.5\ GJ/m^2$ and $C_E = 0$. The life cycle savings in the residential sector is higher than that in the commercial sector due to a higher fuel cost. As shown in Figure 6.3.1, the life cycle savings for an existing building with gas heating is usually negative for a five-year period of economic analysis ($2.5 < P_1 < 5.0$), depending on the economic parameters P_1 and P_2. For a new building with gas heating, the life cycle savings is usually positive, as shown in Figure 6.3.2.

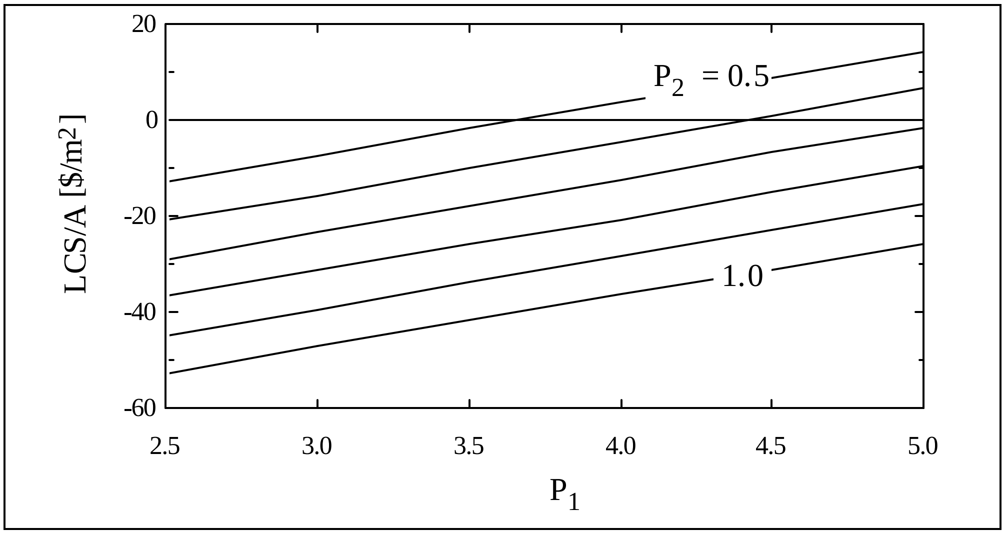

Figure 6.3.1. Life cycle savings for an existing building with gas heating.**{** TC "Figure 6.3.1. Life cycle savings for an existing building with gas heating." \l 5 **}**

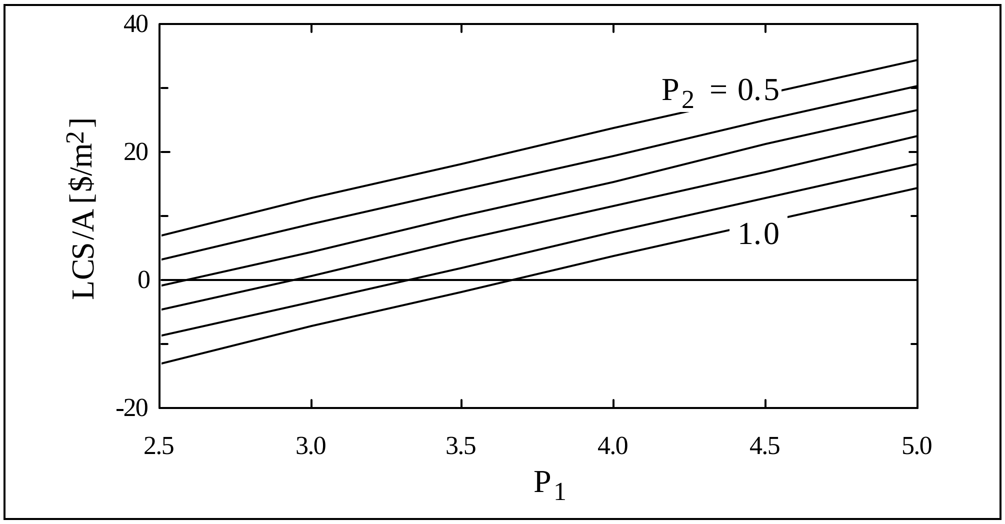

Figure 6.3.2. Life cycle savings for a new building with gas heating.**{** TC "Figure 6.3.2. Life cycle savings for a new building with gas heating." \l 5 **}**

As shown in Figures 6.3.3-4, the life cycle savings for existing and new buildings with electric heating is always positive for a five-year period of economic analysis.

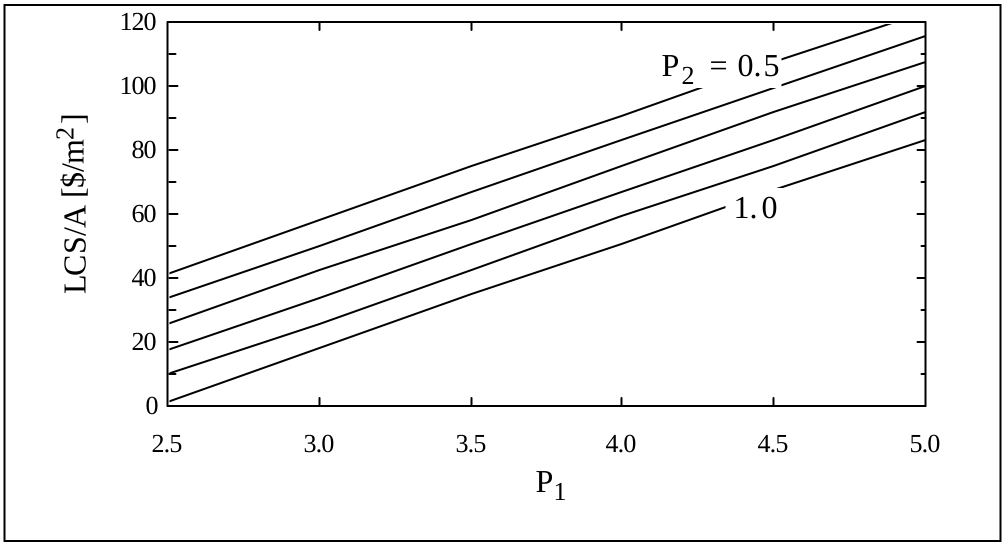

Figure 6.3.3. Life cycle savings for an existing building with electric heating.{ TC "Figure 6.3.3. Life cycle savings for an existing building with electric heating." \l 5 }

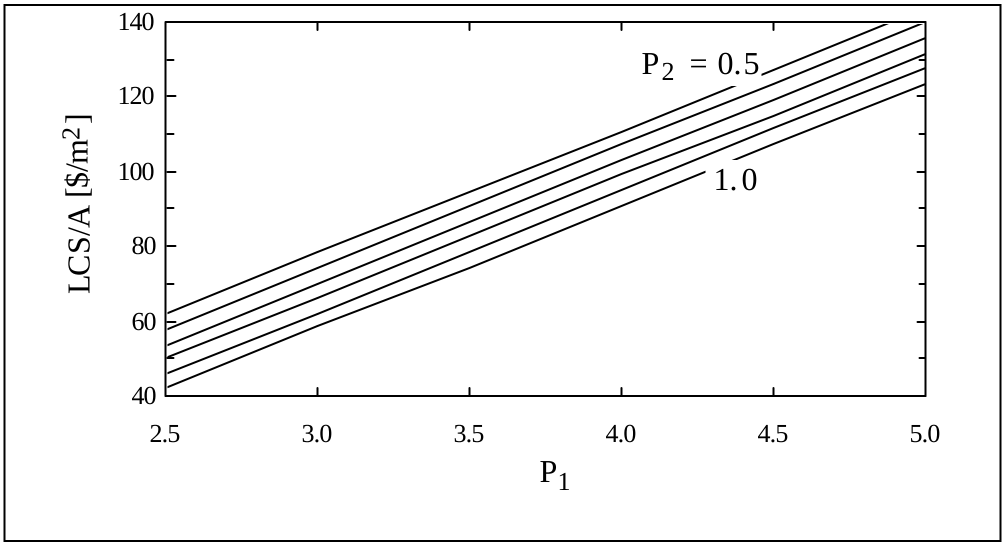

Figure 6.3.4. Life cycle savings for a new building with electric heating.{ TC "Figure 6.3.4. Life cycle savings for a new building with electric heating." \l 5 }

The minimum ratio P_1/P_2 which yields a positive life cycle savings is calculated from Equation 6.2.12 and is shown in Table 6.3.1. For those readers not familiar with the P_1,P_2 method of life cycle savings, the minimum ratio P_1/P_2 from Equation 6.2.12 is also the simple payback period in years.

Table 6.3.1. Minimum P_1/P_2 ratios for positive LCS in the residential sector.**{** TC "Table 6.3.1. Minimum P_1/P_2 ratios for positive LCS in the residential sector." \l 7 **}**

Building, fuel type	C_A [\$/m^2]	C_F [\$/GJ]	P_1/P_2
New, electric	40	21.83	1.22
Existing, electric	80	21.83	2.44
New, gas	40	7.27	3.67
Existing, gas	80	7.27	7.34

UTC systems may have a significant statewide potential for use in the residential sector on existing large apartment buildings with electric heating. It is difficult to determine the magnitude of the potential because statewide data are not available on the number of large apartment buildings with electric heating. UTC systems should also be considered for new large apartment buildings with gas or electric heating. UTC systems on smaller residential buildings would have insufficient collector areas for operation.

6.4 Agricultural Sector{ TC "6.4 Agricultural Sector" \l 2 }

The feasibility of using UTC systems to pre-heat ventilation air for poultry and livestock shelters is explored. UTC systems for crop drying and storage are not considered.

UTC systems on swine shelters are simulated for two cases: a shelter with only 18-kg growing pigs and a shelter with only adult pigs. The ventilation rate guidelines are given in Table 6.4.1 [ASAE, 1995]. A value of 0.001 m^3/s-sow is used for the growing pigs and 0.01 m^3/s-sow for the adult pigs.

A face velocity of 0.04 m/s is chosen, which yields collector areas of 0.025 m^2/sow for the growing pigs and 0.25 m^2/sow for the adult pigs. Since UTC systems require large collector areas to operate at maximum efficiency, only large farms are well-suited for UTC systems. As seen in Table 6.4.2 [Wisconsin Agricultural Statistical Service, 1995], most of the swine farms in Wisconsin are small. The collector areas in Table 6.4.2 are calculated using 0.25 m^2/sow. For small farms, the collector area is not large enough to operate a UTC system.

Table 6.4.1. Ventilation rate guidelines for swine.**{** TC "Table 6.4.1. Ventilation rate guidelines for swine." \l 7 **}**

Swine	Winter minimum ventilation rate [m^3/s-sow] 10^{-2}	Winter maximum ventilation rate [m^3/s-sow] 10^{-2}
Sow and litter	0.95	3.7
Growing pigs:		
9-18 kg	0.095	0.71
18-45 kg	0.24	0.95
45-68 kg	0.33	1.18
68-95 kg	0.47	1.65
Gilt, sow, or boar:		
91-114 kg	0.47	1.65
114-136 kg	0.57	1.89
136-227 kg	0.71	2.12

Table 6.4.2. Swine farm size in Wisconsin.**{** TC "Table 6.4.2. Swine farm size in Wisconsin." \l 7 **}**

Farm size [pigs]	Farm Number	Avg. Size [pigs]	Avg. A [m^2]
1-99	5000	20.8	5.2
100-499	2000	176.8	44.2
500-999	420	594.3	148.6
1000-1999	130	1280.0	320.0
2000+	50	3328.0	832.0
All Farms	7600	136.8	34.2

The lowest optimum temperature is 10 C for adult swine and varies with age for growing pigs [ASAE, 1995]. An average value for growing pigs is 20 C. However, the balance temperature, as calculated from Equation 6.2.1, is higher for shelters with adult pigs than for those with growing pigs, as shown in Table 6.4.3. The growing pigs generate about 100 W/pig, and the adult pigs generate about 250 W/pig [ASAE, 1995]. More growing pigs than adult pigs can be housed in the same building: it is assumed that five 18-kg growing pigs need the same space as an adult pig. Therefore, the internal gain in a shelter for growing pigs is high, causing a low balance temperature. The balance temperatures in Table 6.4.3 are highly-dependent on the shelter UA-value, but for any reasonable UA-value the balance temperature of the growing-pig shelter is lower than for the adult-pig shelter.

Table 6.4.3. Simulation results for UTC systems on swine shelters.**{** TC "Table 6.4.3. Simulation results for UTC systems on swine shelters." \l 7 **}**

Swine	Q_{save}/A [GJ/m^2]	T_{bal} [C]
Growing pigs	0.64	-1.5
Gilt, sow, or boar	0.80	1.5

As shown in Table 6.4.3, both swine shelter simulations yield low energy savings due to the low balance temperatures. Compare the energy savings in Table 6.4.3 to $Q_{save}/A = 1.5$ GJ/m^2 for the commercial sector (see Table 6.2.1). UTC systems do not have a significant statewide potential for use on swine shelters due to the low energy savings and the need for large collector areas.

Dairy cows, beef cattle, and poultry are productive in low temperatures [ASAE, 1995]. Simulations of UTC system on shelters for these animals are not performed. There is no significant statewide potential for use of UTC systems on livestock or poultry shelters.

6.5 Industrial Sector{ TC "6.5 Industrial Sector" \l 2 }

Statewide data is not readily available to estimate the technical potential of UTC systems in the industrial sector. Regardless of the technical potential, the economic potential of UTC systems in the industrial sector is insignificant.

Many industrial buildings have a low balance temperature due to a low room temperature or significant heat generation internally from industrial processes. As seen in previous sections in this chapter, a low balance temperature yields a low energy savings. Not all industrial buildings have a low balance temperature, though.

Significant energy savings on industrial buildings is possible if they have the following two characteristics: high balance temperature and high outdoor air requirement. However, this energy savings does not translate into life cycle savings unless the building uses electric heating, as seen in previous sections in this chapter. Since a negligible fraction of industrial buildings use electric heating [Wichert, 1995], there is no significant economic potential for UTC systems in the industrial sector.