A study of energy use in worship centers is presented along with recommendations for designing new buildings and improving existing buildings

Design for the Future by Looking at the Past

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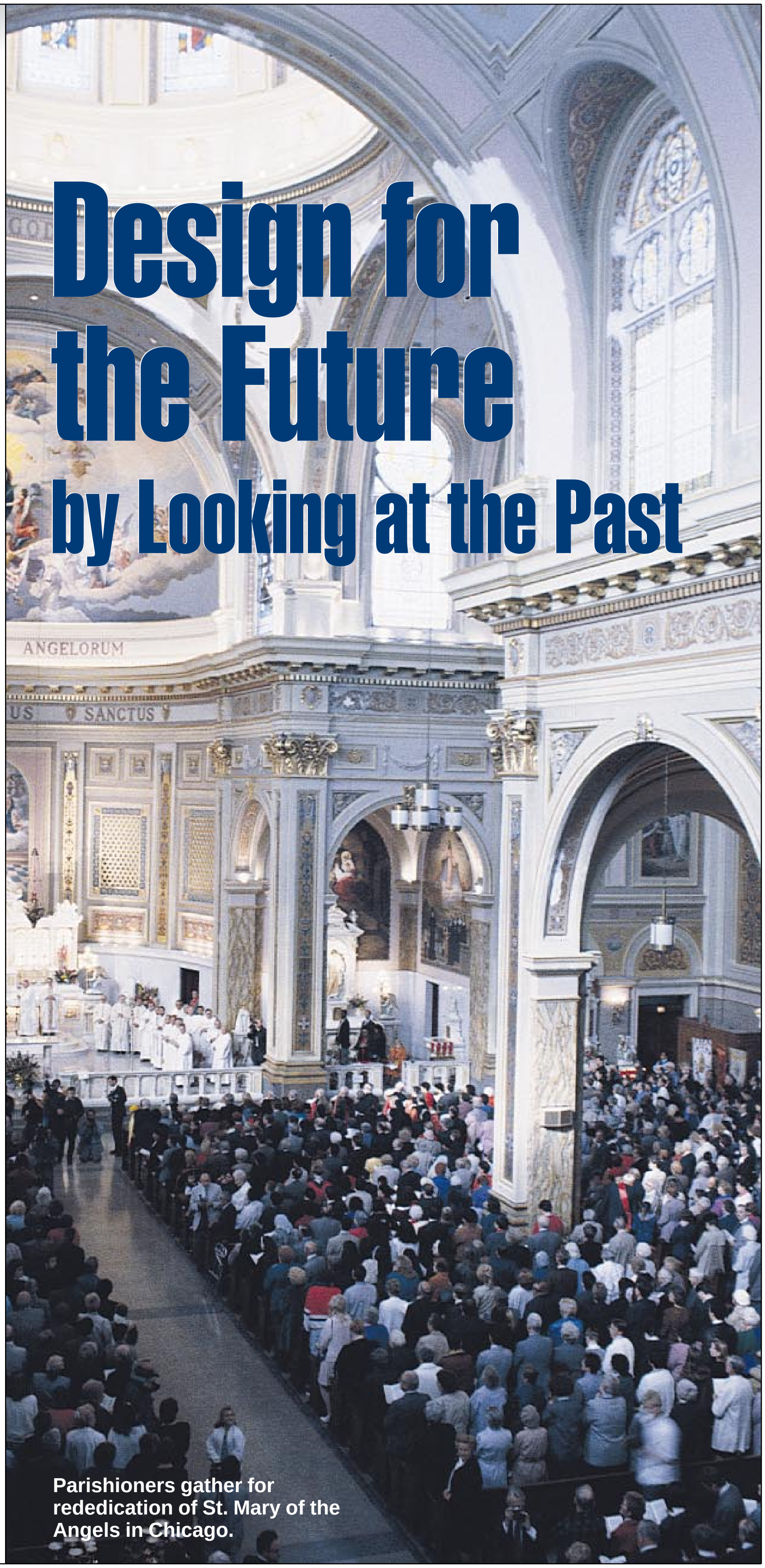
This article describes experience with energy use in houses of worship. It presents metered energy data from 302 churches, synagogues, mosques, and other places of worship in and around Philadelphia. The buildings average 16,700 sq ft. Each building has its own utility meters and does not share fuel storage tanks with any other building. The average energy budget is 64,400 Btu and $0.72 per sq ft per yr.

Background

The Interfaith Coalition on Energy (ICE) was started in 1980 by the religious community in Philadelphia, with financial support from foundations and corporations. During the past few years, ICE has continued its work with support from local religious denominations and from fees for service, mostly on-site surveys of the buildings and their energy systems. Data from each separately metered building are entered into a database. This article is based on



Parishioners gather for rededication of St. Mary of the Angels in Chicago.

Photo by Neal Vogel

those data. An earlier summary was published in February 1988.[1]

To date, ICE has conducted on-site energy surveys for over 460 congregations with over 1100 buildings. It has published more than 60 newsletters and conducted over 200 energy management workshops.

Methodology

When a congregation expresses interest in an ICE energy survey, it must first sign forms to authorize the release of information about its energy consumption. Energy data are gathered from the utilities and fuel suppliers before each survey. After the survey report has been completed, the energy data, as well as data from direct observation of the building and its energy systems, are entered into a relational database.

The age and type of building are two of the data fields. For this article, the database was separated by age into seven groups of 34 to 54 worship centers. The age groups were selected to get about the same number of buildings in each group. Worship centers are defined as buildings that contain a worship space that is used once or more weekly. The building may also contain offices and classrooms. In many buildings, the classrooms are used for child care during the week. These 302 worship centers are fairly similar.

For the entire group of worship centers, the average cost of energy is $0.69 per hundred cu ft of natural gas, $0.97 per gal of No. 2 fuel oil, and $0.13 per KWH. The high cost per kilowatt-hour is attributable to the electric demand cost in buildings with relatively low hours use. Many of these buildings have an off-peak electric rate with reduced demand charges. Without the off-peak rate, electric cost would be even higher.

In each age group, the use of the buildings is about the same. The use of the buildings has been estimated by calculating the hours use of peak monthly electric demand. For buildings with measured demand, the monthly kilowatt-hours are divided by the monthly peak measured demand in kilowatts, resulting in the hours use of demand. The 12 months of hours use are averaged for the year and entered into the database. The average hours use of demand for all 302 worship centers is 119, or almost 30 hr per week. Newer buildings have slightly more hours use (Table 1).

TABLE 1—Energy characteristics of worship centers by building age.

Age, years	Number of buildings	Floor area, sq ft	Btu per sq ft per yr		Hours use
			Electric	Fuel	
0 to 20	34	18,112	16,997	46,379	134
21 to 30	36	16,344	10,366	53,499	123
31 to 50	44	17,701	8,091	59,822	129
51 to 70	45	17,147	5,257	62,844	108
71 to 90	45	20,427	5,317	58,002	108
91 to 120	54	15,596	5,379	55,983	117
Over 120	44	11,978	7,199	56,153	113
	Averages:	16,758	8,372	56,097	119

Heating

Overall, newer buildings use less fuel per square foot than older buildings, and the newest buildings use the least of all. For buildings older than 20 years, the annual fuel cost per square foot varies between $0.39 and $0.46. For those newer than 20 years, the annual fuel cost averages $0.32 per sq ft. Similarly, the proportions of fuel costs of total energy costs is about one-third for buildings newer than 20 years and one-half to two-thirds for those that are older. Most buildings over 20 years old have little or no insulation. Thus, newer insulated buildings are saving $0.07 to $0.14 per sq ft per yr.

Average heating energy use for oil heated buildings is 59,259 Btu per sq ft. For gas heated buildings, it is 60,699 Btu per sq ft. Average heating energy use for buildings with one-pipe steam systems is 69,275 Btu per sq ft. For two-pipe steam systems, it is 59,824 Btu per sq ft. Buildings with hot water systems use 55,898 Btu per sq ft while those with warm air systems use 53,678 Btu per sq ft. The higher energy use for steam systems is probably caused by greater heat losses. Electric use in steam heated buildings is lower since fans and pumps are not usually used.

For most buildings, the database contains the Btuh input capacity of the heating system per square foot of heated floor area. For all the age groups, the heating capacity per square foot is about the same. Buildings older than 90 years are slightly higher, and those younger than 50 years are slightly lower (Table 2). Note that installed capacity is usually more than twice the design heat loss.

About one-quarter of older worship centers have a single heating

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TABLE 2—Heating system characteristics by building age.

Age, yr	Percent with			Input capacity, Btuh per sq ft
	One heating zone	7 to 13 heating zones	Steam heat distribution	
0 to 20	4	37	12	75
21 to 30	12	15	6	81
31 to 50	10	12	41	79
51 to 70	31	10	87	86
71 to 90	21	12	80	86
91 to 120	25	8	68	88
Over 120	32	10	47	88

[1]*Superscript numerals indicate references listed at end of article.*

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zone. One in ten have 7 to 13 zones. The ratios reverse for newer buildings. More than half the worship centers over 30 years old have steam heat. Only one in ten newer than 30 years old has steam heat. Improved thermal quality of the building envelope, in addition to higher internal gains, lowers the heating capacity per square foot in newer buildings.

In all age groups, over half the buildings control space temperature with standard, non-timed (non-setback) thermostats. One-quarter to one-third use temperature controls with a timed 7-day cycle. About one in eight uses 24-hr clock thermostats. In worship centers less than 20 years old, there were no 24-hr clock thermostats (Table 3). In the 302 buildings, there were two energy management systems.

About 4 percent of these worship centers have outdoor reset controls that cycle burners for steam or modulate the temperature of circulating hot water in proportion to outside temperature. In almost every instance, these controls are either disconnected or pinned to their maximum settings. Based on conversations with building operators, these controls clearly restrict the ability of the boilers to recover quickly from low temperatures during unoccupied times. Reset controls are most common in worship centers between 20 and 50 years old.

There is no correlation between the age of worship centers and number of heating zones. Worship centers with more heating zones tend to have higher hours use of demand and use more electricity and less fuel (Table 4).

Air conditioning

Newer buildings are more likely to have air conditioning. Two-thirds of the 98 worship centers that are over 90 years old have no air conditioning. One in eight have central air conditioning. Only 10 percent of the newest worship centers do not have air conditioning, and 70 percent of the systems are central (Table 5).

As air conditioning becomes more prevalent in newer worship centers, the peak electric demand increases. Maximum watts are determined by dividing the highest measured electric demand by the square feet of conditioned floor space. The 188 worship centers older than 50 years average about 1.4 watts per sq ft. With central air conditioning, the peak demand doubles and triples. In the newest worship centers, where central air conditioning is most prevalent, the annual energy costs are 50 percent higher than older buildings. This far outweighs the influence of more efficient fluorescent lighting and lower annual fuel heating consumption.

Air conditioning increases electric costs. In worship centers without air conditioning, the average annual electric cost is $0.18 per sq ft. For those using window air conditioners, the average annual electric cost is $0.23. In cen-

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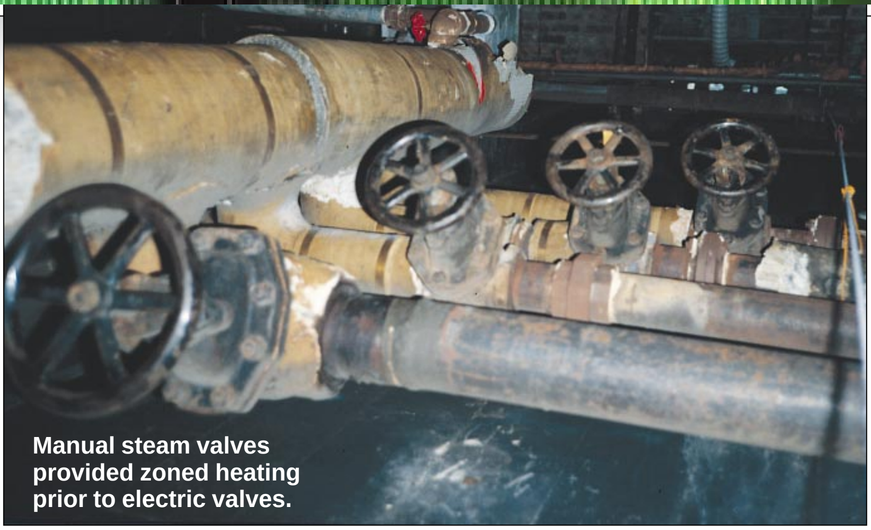

Manual steam valves provided zoned heating prior to electric valves.

TABLE 3—Types of thermostatic controls by building age.

Age, yr	Percent with controls: Standard	24-hr	7-day	Reset
0 to 20	61	0	39	3
21 to 30	55	13	32	13
31 to 50	66	24	18	11
51 to 70	65	10	25	3
71 to 90	63	14	23	0
91 to 120	50	17	33	2
Over 120	55	12	33	0
Averages:	59	12	29	4

TABLE 4—Energy use by heating zones.

Number of zones	Number of buildings	Btu per sq ft per yr: Electric	Fuel	Total	Hours use	Average age
1	58	7,157	60,005	67,162	85	98
2	48	8,648	56,290	64,938	86	83
3	47	6,128	62,522	68,650	98	64
4	36	6,141	60,513	66,654	115	76
5	28	7,614	53,856	61,470	101	63
6	26	7,984	49,424	57,408	114	59
7	15	6,246	49,209	55,455	121	62
8	8	12,030	66,269	78,299	150	48
9	4	19,569	46,166	65,735	133	37
>9	12	11,817	40,770	52,587	134	62
Total:	282					

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trally cooled worship centers, the cost is $0.61 per sq ft (Table 6).

Lighting

Table 5 also shows that lighting in newer worship centers is more likely to be fluorescent. While only one in eight newer buildings has mostly incandescent lighting, for older buildings the ratio is about one in three.

In 1929, the standards for lighting worship space from the Illuminating Engineering Society (IES) suggested 2 to 3 foot-candles at hymnal height in worship spaces. By 1981, the recommended light level had increased to 10 to 15 foot-candles for normal congregations, and 30 foot-candles for "churches with special zeal."

ICE measures the levels of lighting in sanctuaries. Typical measurements show 3 to 6 foot-candles of artificial light. ICE worked with the IES Committee for Lighting Houses of Worship to develop IES Standard RP-25-91, *Lighting for Houses of Worship.*[2] The new standard allows for greater variation in lighting levels based on the characteristics of the worship space and its congregation. Traditional worship space has lower levels of artificial light. Newer buildings have higher lighting levels, which also increases the air conditioning load.

The bottom line

The electric costs in older worship centers are about one-third of the total energy cost. In worship centers newer than 20 years, fuel costs represent one-third, and electricity becomes two-thirds (Table 7).

What factors are responsible for these trends? Since the cost of living index has roughly paralleled the cost of energy index, the economic parameters that influenced design have not changed significantly over time. The changes in energy use and cost, therefore, are driven by design and operation.

Natural ventilation

Older worship centers, and places of public assembly in general, had massive ventilation systems to remove humidity. Before the popularity of automobiles, members of congregations were more likely to walk to wor-

ICE Effectiveness

After completing each energy survey, ICE has a follow up program. One and two years later, metered energy data are again collected. Comparisons are made with pre-survey data to find out how much energy use has been reduced. The results are sent to each congregation. This helps them to see their progress and also provides feedback on the energy recommendations.

The average cost saving was over $3200 per congregation for two years.[1] If each of the 330,000 congregations in the United States and Canada followed the example set by these Philadelphia congregations, the saving to the religious community would be more that $0.5 billion per year.

TABLE 5—Air conditioning and lighting by building age.

	Percent with			
Age, yr	No air conditioning	Central air conditioning	Incandescent lighting	Maximum watts per sq ft
0 to 20	9	70	12	4.18
21 to 30	30	39	14	3.16
31 to 50	31	38	23	2.32
51 to 70	59	11	31	1.38
71 to 90	47	10	20	1.29
91 to 120	60	9	22	1.46
Over 120	69	13	34	1.90

TABLE 6—Electricity use and costs by type of air conditioning.

Type of cooling	Number of buildings	Hours Use	KWH per sq ft	Electricity cost per sq ft, $
No air conditioning	109	100	1.3	0.18
Window units	103	121	1.7	0.23
Central air conditioning	52	127	4.5	0.61

Dormer vents provide natural ventilation for this church. Overnight summer cooling reduces air conditioning loads.

TABLE 7—Annual energy costs per square foot.

		Annual energy costs, $ per sq ft				
Age, yr	Number	Fuel	Percent	Electric	Percent	Total
0 to 20	34	0.32	34	0.61	66	0.93
21 to 30	36	0.39	49	0.40	51	0.79
31 to 50	44	0.40	55	0.33	45	0.73
51 to 70	45	0.46	68	0.21	32	0.68
71 to 90	45	0.43	67	0.22	33	0.65
91 to 120	54	0.42	65	0.22	35	0.64
Over 120	44	0.41	59	0.29	41	0.70
	Averages:	0.41	57	0.31	43	0.72

ship. Their clothing was more absorbent than now. The ceilings and attics of older worship spaces have elaborate openings to allow warmer air to escape. In most all cases, these openings are capable of being closed when not needed, such as during the coldest winter months. When left open during the summer, overnight air can cool the building and its contents. Modern design seals the buildings and uses mechanical ventilation with air conditioning. This is more expensive than natural ventilation and may lessen the quality of indoor air.

Envelope thermal quality

The thermal quality of the building envelope has little impact on heating energy in intermittently heated buildings. In 1995, ICE helped Inspired Partnerships in Chicago with computer energy modeling of a typical old church in Evanston, Ill. This work was funded by the National Park Service. The analysis showed that a second layer of glazing over stained glass windows causes minimal changes in energy use.

The congregation paid $7544 for installation of a double glazing over five large stained glass windows. The annual energy cost savings were calculated by using weather data for other cities (Table 8).

The saving in Evanston was $180 while the maximum saving was $200 in the coldest city—Toronto, Canada. If the church was in Phoenix, the glazing would pay for itself in over 1500 years. The same computer simulation showed that the use of clock thermostats saves five times as much heating energy as the secondary glazing in Evanston. These savings are shown by data in Table 9.

In intermittently heated buildings, temperatures are lowered during unoccupied periods to reduce fuel costs. The cooler building interior is a heating load that is separate from and in addition to the external load. Improving the thermal quality of the envelope does not reduce the internal heating load. Insulated worship centers have slightly smaller heating systems than uninsulated ones (Table 10).

TABLE 8—Annual savings and payback periods for secondary glazing.

Location	Unvented glazing: Savings, $	Unvented glazing: Payback, yr	Vented glazing: Savings, $	Vented glazing: Payback, yr
Evanston, Ill.	180	42	95	80
Seattle, Wash.	137	55	70	108
Toronto, Ont.	200	38	105	72
Phoenix, Ariz.	5	1511	8	944
Savannah, Ga.	23	328	13	581

TABLE 9—Energy use by type of temperature control.

Type of thermostat	Number of buildings	Fuel, Btu per sq ft per yr
Standard	164	60,574
24-hr	34	52,136
7-day	81	50,864

Rigid coverings on stained glass not only save minimal heating energy but can trap heat and moisture, which ruin the window and its frame. *Photo by Jean Farnsworth*

Steam heat systems

In heating worship centers, distribution of heat by steam has many advantages over hot water. In addition to quicker recovery from low space temperatures, steam radiators provide radiant heat as well as convective. Low space temperatures during unoccupied periods may cause water to freeze in perimeter heating pipes whereas steam condensate returns to the boiler room.

Congregations prefer simpler, standard thermostats over digital controls. Outdoor temperature reset systems are almost always disabled after they are installed. Table 9 shows energy data based on the type of temperature control system.

Worship centers with 24-hr clock thermostats use 14 percent less fuel per square foot than those with standard thermostats. Worship centers with 7-day clock thermostats use 16 percent less. Based on average building size and fuel cost, 24-hr clock thermostats save about $1000 per year in heating costs. A 7-day temperature control saves almost $1200 per year, about the same as shown in Table 9.

Some conclusions

Congregations trying to reduce their operating costs can learn from these data that energy costs are lower in older buildings. Codes, standards, and innovations in building design have not produced worship centers that use less electricity. Simpler temperature controls are preferred even though timed controls save money. Central air conditioning is expensive to install and operate.

Reductions in heating fuel by improving thermal quality are modest at best (Table 10). Assuming that buildings less than 20 years old are insulated and older ones are not, the difference in annual heating costs is about $1400 for an average size worship center. The input heating capacity has decreased by 10 Btuh per sq ft, so there is little savings on the size of the heating system. This is likely due to the need to recover quickly from lower temperatures during unoccupied times and an internal heating load of building contents and mass that insulation does not decrease.

Behavioral factors

The most consistent, and least documentable, factor in energy consumption of worship centers involves the people who operate them. Congregations have decentralized decision-making processes. A 1992 report[3] shows that full-time custodians are paid an average of $15,831 per year. Part-time custodians are paid an average of $7.16 per hr for an average of 12 hr per week. Since most temperature control is manual, there is greater reliance on human behavior to control energy costs in worship centers. In spite of low pay, worship centers use less energy per square foot compared with other building types.

Because of the importance of attitude and behavior, ICE supports including operation and maintenance requirements in ANSI/ASHRAE/IESNA Standard 100-1995, *Energy Conservation in Existing Buildings*.[4] For the first time, existing buildings can be judged according to how they are operated as well as by how they are constructed. Standard 100 is a voluntary standard that suggests that building operators have ready access to a facility operations manual. They should follow manufacturers' instructions, readily retrievable from a preventive maintenance file; receive feedback on energy usage; and reasonably strive to maintain energy use below the average of similar buildings in a similar climate.

These are the most important aspects of energy management in worship centers based on measured data and on-site observations. Similar conclusions apply in many other types of intermittently occupied buildings.

TABLE 10—Comparing newer and older worship centers.

Age, yr	Number of buildings	Btu per sq ft per yr			Heating fuel input, Btuh per sq ft
		Electric	Fuel	Total	
20 or less	34	16,997	46,379	63,376	75
Over 20	268	6,762	57,799	64,558	85

Recommendations

Based on this analysis of metered data, the following recommendations are made.

Heating costs in newer insulated and double glazed buildings are $0.07 to $0.14 lower than mostly uninsulated buildings. Thus, it is very difficult to justify improving the thermal quality of older buildings. Improving the thermal quality in new construction is often hard to justify.

The installed capacity of heating systems should be at least twice the design heat loss. This allows rapid recovery from temperature setback. For intermittently occupied buildings, setback to 45 F is worthwhile.

The average heating energy for buildings with standard thermostats is 60,574 Btu per sq ft. Buildings with 24-hr clock thermostats used 52,136 Btu per sq ft while those with 7-day controls used 50,864 Btu per sq ft. Thus, setback is worthwhile. Hot water reset cannot be justified for this building type. Zoning reduces fuel consumption. Diverse use of these buildings justifies multiple zones.

HPAC

References

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2) *Lighting for Houses of Worship*, IES publication RP-25, IESNA, 120 Wall St., 17th Floor, New York, NY 10005.

3) *1992 Church Compensation Report*, Christianity Today, Inc., 465 Gundersen Rd., Carol Stream, IL 60188.

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