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Energy Simulation of Historic Buildings: St. Louis Catholic Church, Castroville, Texas

ANAT GEVA

Application of computer simulation to a systematic analysis of energy performance of historic structures may uncover inherent climatic qualities, as well as provide energy conservation strategies.

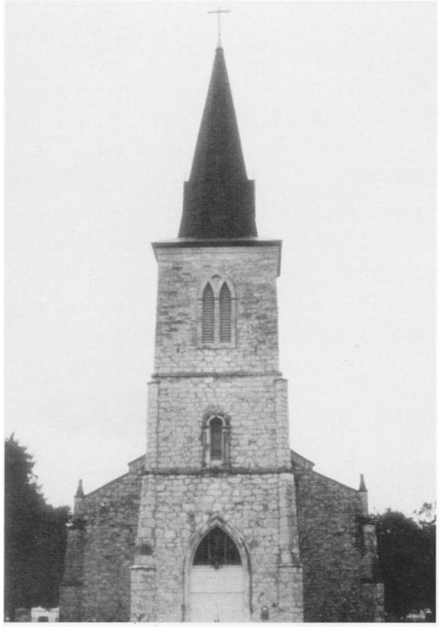

Fig. 1. St. Louis Catholic Church, front elevation. All illustrations by author.

Introduction

Incorporating climatic considerations into the preservation process requires sensitivity. When a building exhibits thermal comfort, it is desirable to preserve and restore its "inherent" energy-savings features. Historic buildings with climatically incompatible construction require special attention.

The balance between preservation objectives and thermal needs is addressed in several design strategies and guidelines, which cover environmental considerations, energy benefits of the building's features, and potential design strategies. Vonier (1981) in *Energy Conservation and Solar Energy for Historic Buildings Guidelines* recommends considering site elements, such as vegetation, which provide natural shading and help to minimize heat gain; retaining original roof features; evaluating the thermal properties of building materials; reducing air infiltration at openings; taking advantage of daylight; and retaining original high ceilings, especially in hot, humid areas, where they provide natural convection. Smith (1978) in *Technical Preservation Brief 3* emphasizes the importance of the "inherent energy savings characteristics of historic buildings" and suggests passive and retrofitting measures to conserve energy (e.g., walls and roof insulation, natural ventilation, air infiltration). Park (1991) in *Technical Preservation Brief 24* suggests ways to include mechanical systems in historic buildings. Essentially, the described guidelines attempted to integrate general recommendations of "design with climate" that were developed by scholars such as Olgyay (1973), Givoni (1976), Robinett (1983), and Lechner (1991), with responsible preservation objectives as set forth in the *Secretary of Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings*.

Most energy-related design guidelines and recommendations are based on case studies and practical experience. The objective of this study is to introduce a systematic, quantitative approach to determining energy needs of historic buildings. Using computerized energy simulations, the study proceeded in three major steps: the evaluation of the comfort level and energy performance of the building in both its original and current conditions, the development of energy strategies to improve thermal conditions while maintaining historic integrity, and the selection of an approach based on these findings.

This paper demonstrates the application of this approach to St. Louis Catholic Church in Castroville, Texas. However, the implications of this research apply to other historic buildings in different climates.

Background

St. Louis Catholic Church was constructed in 1868 by immigrants from Alsace, France, who brought with them a deep sense of religion and heritage. They were quick to organize their congregation and build churches (Barnes 1982; Driskill and Grishham 1980). The fact that this gothic-style church[1] was built with no mechanical systems in a hot, humid area in Texas and intended to resemble the churches in a cold region in France made this building a good selection for this study.

The church is a single rectangular nave 156 by 50 feet in plan, one-story high, and built with thick, local limestone walls. It has a pitched, arched ceiling with exposed, wooden roof trusses. The double-pitched roof is covered with wooden shingles. Stained-glass windows imported from Europe and Galveston illustrate the history of St. Louis, King of France. The bells were cast in West Troy, New York, in 1870. When constructed, the church was one of the largest in Texas (Fig. 1).

Information on the church's architectural features was obtained from field trips, the Historic American Buildings Survey (HABS), and the Architectural Drawings Collection in the University of Texas at Austin. These records include drawings, pictures, documents, and references. The data were coded into ENER-WIN, a computerized energy simulation program developed at Texas A&M University (Degelman et al. 1991, 1994, 1995).[2]

Research Instrument

The ENER-WIN simulation software evaluates the comfort level of buildings with and without mechanical systems. It assesses the energy performance of buildings in energy units and in dollars required to achieve designated climatic conditions by performing an hour-by-hour energy simulation based on given climatic, building, and economic data. The software includes a weather database of more than 280 U.S. and foreign cities, an envelope-materials catalog, and numerous user profiles. The program performs zone and building geometry processing, load calculations, energy summations, and life-cycle cost predictions based on present value and escalation factors for the building and its energy use.

Procedure

Two major steps are involved in the basic operation of this program: creating the input file and running the simulation.

Creating input files. Fig. 2 illustrates the schematic structure of creating an input file. The input coding requires general information about the building (such as building type, year of construction, floor area), weather data, architectural features, and occupancy patterns.[3] Two input files were prepared: one described the church in its *original* conditions, the second included information on subsequent changes and the *current conditions.*

The input file for the original conditions included:

- Project information: project name; building type (the pull-down menu does not include "church," so a "theater/cinema" was selected since it has a similar thermal behavior); year of construction (1868); building orientation to the north (45° NE); total floor area (7886 sq.ft.); number of days per week during which the building is fully occupied (Sunday and Wednesday).
- Weather data: information on temperature, relative humidity, solar radiation, and wind velocity were obtained from the weather database (Degelman 1990).[4] Since Castroville was not included, the region's major city, San Antonio, was used as a surrogate site.
- Economic data: related to the economic life cycle of a building. They are important in simulations of new designs. In this study program default data were used.
- Architectural data: a sketch of the geometry of the plan and description of zones. To increase the efficiency of the energy simulation, ENER-WIN requires dividing the building into functional zones. Since the church has one story with one large open space, it was defined as one zone. The required input for the zone is its user profiles and the thermal values of its envelope.

Hourly user profiles included occupancy (700 members who met twice a week in the late nineteenth century); natural ventilation, which implies that windows are open when outdoor conditions permit [in this case the program recommends a natural ventilation rate of 4 cfm/sq.ft. or 7.5 cfm per person (Degelman 1995)]. Thermostat setting (irrelevant to this input file) is required for running the simulation [the temperature (in F°) in the church was set as follows: summer occupancy, 77°; summer unoccupancy, 90°; winter occupancy, 72°; and winter unoccupancy, 50°; hot-water, mechanical ventilation, and light (not applicable to the original church and not used in this simulation)].

For envelope materials the U-Factor, thermal time lag, and a decrement factor[5] for the floor, walls, roof, and openings were calculated using MATERL4 software program.[6] The data were based on tables in the ASHRAE fundamentals book (1985).[7] The envelope included the following: foundation (the crawl space is enclosed with local limestone walls on ledges of loose stone. It is calculated by the program as a basement); walls (24- to 26-inch-thick local limestone plastered only in the interior); floor (large pieces of flagstone); roof (double-pitched roof with a slope of 30° each, covered with wood shingles, and having rafters exposed on the interior); opening/wall ratio (0.09); glass type (stained glass imported from Europe and Galveston).

Additional required data: internal mass (masonry structures: 100 to 150 lbs./sq.ft.); area of the walls, roof, floor, and windows (calculated from HABS drawings and from measurements on the site); orientation from north of each element (obtained from HABS drawings); surface exposure to ground cover (i.e. grass, trees, concrete, asphalt derived from archival pictures. The front was exposed to a paved path, the back to grass, and the long facades were exposed to trees); shading (percentage of protection from direct sunshine in summer and winter, estimated from HABS drawings); infiltration rate [varies rates of air changes per hour (ACH), hourly throughout the year as a function of outdoor wind speed and temperature difference between indoors and outdoors (Coblentz-Auchenbach Model, cited in Degelman 1995, p. 28). A default rate of 1.5 ACH for buildings with loose infiltration is used in this study (Degelman 1995)].

The second input file included most data of the previous file and incorporated the alterations. The first notable change was the installation of an HVAC system — a direct expansion (DX) central air-conditioning and a central gas-heating unit — accompanied by sealing the windows and covering the flagstone floor with carpet. These measures reduced the infiltration rates from 1.5 ACH to 1 ACH. In addition, the sealed windows blocked the natural ventilation (0 cfm/sq.ft), a critical factor that adversely affects the heat and humidity inside the church during the warm seasons. It should be acknowledged that an input of 0 cfm/sq.ft implies a complete block of ventilation that omits the effects of opening the door. However, since the church's operating schedule is rather fixed, ventilation from the door is very small and occurs only in limited periods. Furthermore, even if one would simulate current conditions with a small percentage of ventilation (e.g., 0.2 cfm/sq.ft), the influence on the internal comfort would be minimal, since the recommended rate for effective natural ventilation is 4 cfm/sq.ft. (Degelman 1995).

Another important change was the growth of the congregation from 700 members in 1868 to 2,500 in 1996. This expanded occupancy increases radiant heat, which contributes to climatic comfort in winter and adds to discomfort in summer. The second input file also included the contribution of the incandescent lights.

As detailed above, the thermal parameters of the original and current conditions capture the essential features of the church's architecture and occupancy patterns. Moreover, the compatibility of the simulation results (outlined in the next section) with acceptable patterns of climatic effects lends support to their validity. Finally, the simulation results parallel the church's utility use records.

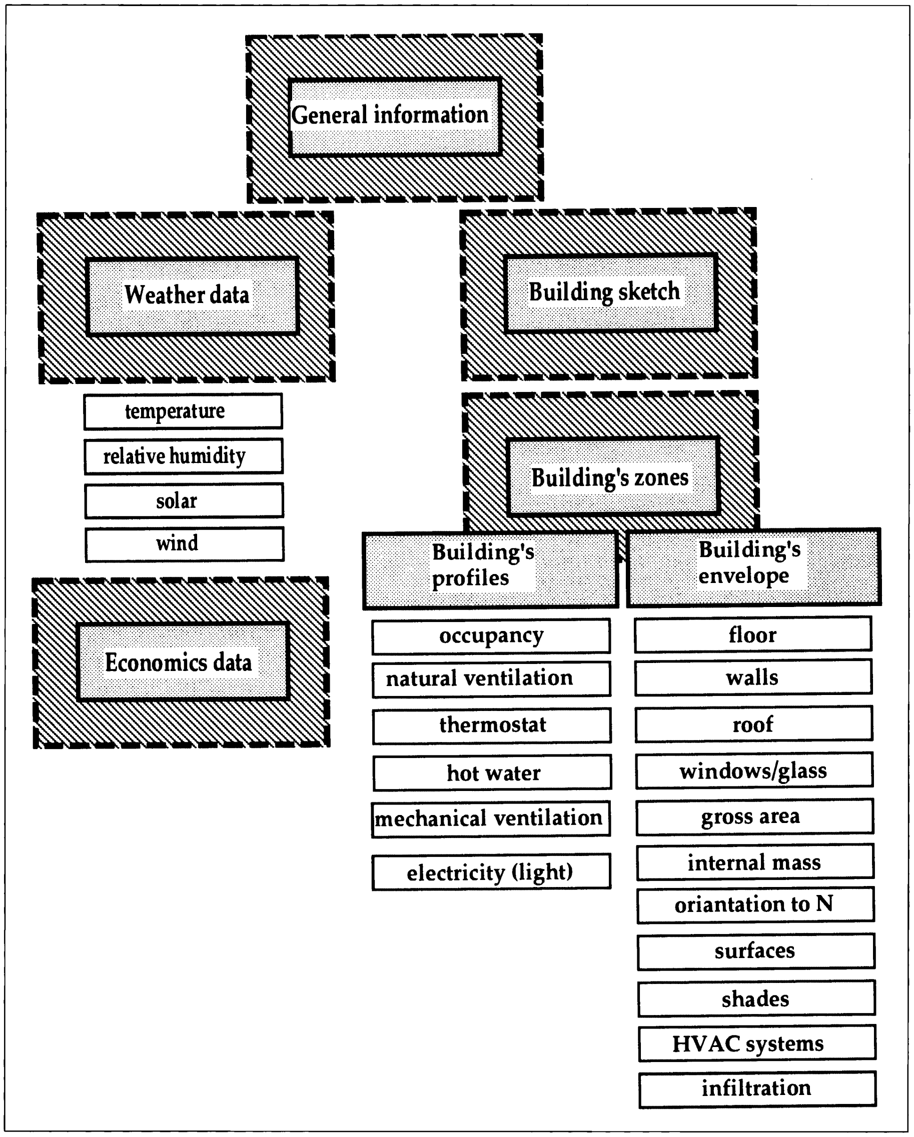

Fig. 2. Schematic structure of input file.

Simulation runs. ENER-WIN's floating space temperatures run and the complete/normal run assessed the internal comfort level and the energy performance required to achieve designated environmental conditions in the building.

Floating space temperatures run applies to structures without HVAC. The space temperature floats through an unrestricted range throughout the year. Setting the lower and upper limits of the temperatures to 1° and 200° (F) eliminates the unintentional "turn-on" of the mechanical systems that never existed. The output illustrates the hour-by-hour hottest and coldest *internal* conditions over the course of a day for each month of the year. In order to assess comfort levels, the simulation provides space temperatures, weighted average interior wall-surface temperatures (MRT), interior relative humidity, and a summary of the operative temperatures expressed by the total discomfort degree hours (DDH).[8] The DDH measure thermal stress exceeding the comfort zone.[9] This output implies an inverse relation between the DDH and the compatibility of the building to the local climate.

Complete/normal run assesses the energy performance of a building with an HVAC system in energy units and in dollars. Results show the building's source energy[10] in thousand Btus per square feet (kBtu/sq.ft.), total energy consumption in million Btus (MBtus), and energy cost analysis. The results detail monthly and annual heating and cooling loads, peak loads, and energy-demand profiles. The more MBtus required to maintain thermal comfort, the less compatible the building is to the climate.

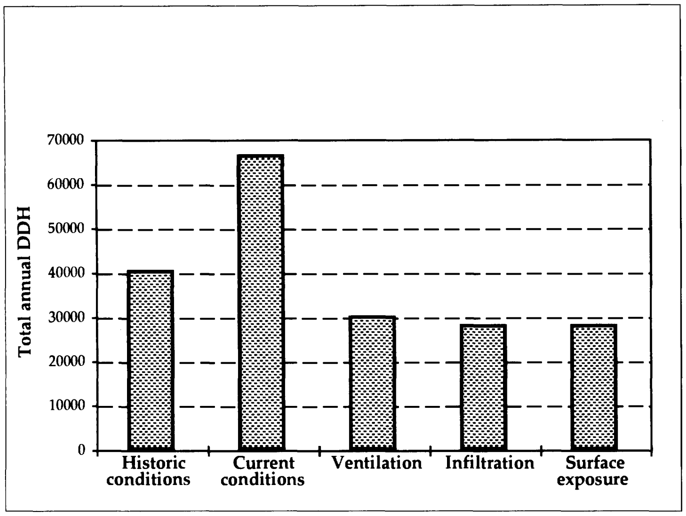

Fig. 3. Total annual discomfort degree hours (DDH).

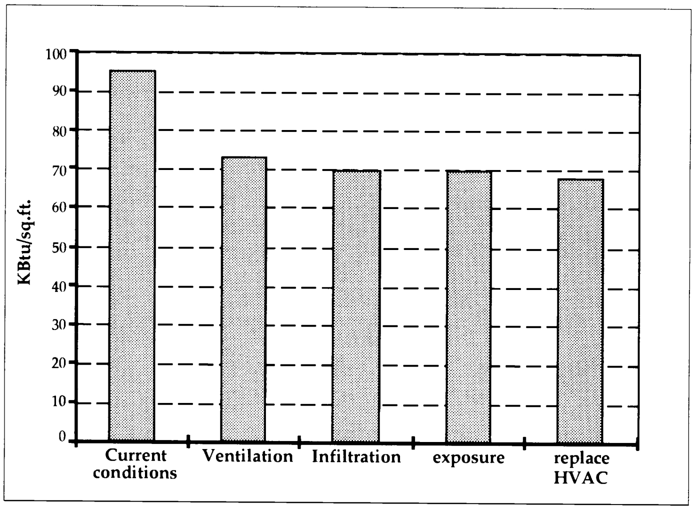

Fig. 4. Source energy in kBtu/sq.ft.

Research Stages and Results

This research consisted of three major stages: identifying energy conservation strategies that can reduce energy consumption while maintaining historic integrity; evaluating the energy strategies on the church; and analyzing the best energy-conservation approach.

The results identify energy-conservation strategies and evaluate them.

Identifying the energy conservation strategies. The results of the floating space temperatures simulation of the original church showed a discomfort level of 39,923 total annual DDH. In the current church, when the HVAC systems are turned off, the discomfort increased substantially to 65,975 total annual DDH. Most current climatic discomfort can be attributed to heat. The thermal conditions in summer worsen from 8,959 annual hot DDH in the original building to 47,856 current annual hot DDH. These findings show that changing some of the original energy components, such as blocking the natural ventilation, had a major impact on comfort. In contrast, the 18,119 annual cold DDH of the recent church expressed more comfort than the 30,963 annual cold DDH of the original church. These can be explained by the increased number of users contributing to heat gain and by the sealed windows that blocked outside cold air.

The normal simulation run evaluated the energy performance with HVAC systems in operation. The results show an annual source energy of 95.2 kBtu/sq.ft.,[11] a total annual heat load of 67.7 MBtu, and a total annual cooling load of 473.2 MBtu. These findings paralleled the results of the annual hot and cold DDH and demonstrated the major impact of the Texas summers on the building's thermal conditions.

The normal simulation run on current conditions not only evaluated energy performance but also pointed out elements that contribute significantly to annual heating and cooling loads. Areas for thermal improvement are: exterior walls, roof, windows, natural ventilation, and infiltration. Treatment of these target areas was analyzed in accordance with conventional energy design guidelines and preservation briefs (Smith 1978, Vonier 1981, Park 1991).

- Exterior walls. Any measure to improve the thermal conditions of the original exterior walls of the church may damage the building's integrity. Therefore, the energy strategy should focus only on the surface exposure adjacent to the walls (e.g., vegetation).
- Roof. Installation of central air-conditioning ducts did not leave enough room for insulation. Adding an interior insulation layer will damage the historic value of the ceiling.

Since the simulation showed that the roof adds only 3 to 4% to the total loss of heat loads, the consequences of insulating the roof were not pursued.

- Windows, natural ventilation, and infiltration. The energy design guidelines and preservation briefs recommend reopening windows. This simple measure is expected to reduce the energy consumption and decrease condensation. Thus, the current ventilation rate should revert to the original value of 4 cfm/sq.ft. At the same time the simulations suggested that the church needs more weathering measures to reduce the infiltration rates from 1 ACH to 0.5 ACH.
- HVAC system. The energy simulation was utilized to evaluate the thermal impact of replacing the DX system with a more efficient fan coil system.

Table 1 summarizes these four strategies and shows the changes in thermal values between original and current conditions of the church:

Evaluating energy conservation strategies. Fig. 3 demonstrates the climatic comfort of the church as a result of incorporating all four energy strategies. In general, floating space temperatures simulations showed that introducing all four changes improved the climatic comfort of the church to a level of

27,817 annual DDH, a 30% improvement over original conditions (39,923 DDH) and a 58% improvement over current conditions (65,975 DDH). Fig. 4 illustrates the effects of the four conservation strategies on the energy performance in source energy (kBtu/sq.ft). The results of the normal runs correspond to the DDH findings. Introducing all four recommended strategies lowered the building source energy performance by 27%, from 95.2 to 67.9 kBtu/sq.ft.

The first simulation runs evaluated adding natural ventilation. The DDH scores obtained by using the floating space temperatures run revealed 29,797 total annual DDH, an improvement of 55% over current conditions and 25% over original conditions. In summer there was substantial improvement (79%) in the annual hot DDH (10,080) over the current 47,856 hot DDH.

The results of the normal run corroborated the DDH findings. Natural ventilation improved the energy consumption of the church by 25%, from 95.2 to 72.9 kBtu/sq.ft. The major impact is observed in summer, when cooling loads are reduced by 32% from 473.2 to 323 MBtu. In winter natural ventilation increased the cold discomfort in the church by 9%, from 18,119 to 19,717 DDH, and heightened the demand for heating by 18% from 67.7 to 80.3 MBtu.

The second simulation runs tested carefully weathering-in the church's openings, i.e., decreased the infiltration rate to 0.5 ACH. This rate, added to natural ventilation, yielded an additional improvement of 7% in climatic comfort and 4% in energy consumption. The resulting 27,769 total annual DDH showed a 30% improvement over original conditions and a 58% improvement over current conditions. This energy strategy reduced the current annual hot DDH by 79%, from 47,856 to 9,895 DDH, and the current annual cold DDH by 1%, from 18,119 to 17,874 DDH. The normal run showed a reduction of 27%, from the current 95.2 to 69.9 kBtu/sq.ft. There was also a 33% improvement of the cooling energy, from the current 473.2 to 316 MBtu. There was a small increase of 2% in heating energy, from 67.7 to 69.1 MBtu.

Table 1. Energy Conservation Strategies: Original and Current Conditions

	Ventilation (cfm/sq.ft)	Infiltration (ACH)	Surface Exposure	HVAC	Number of People
Original conditions	4	1.5	Front: pavement Back: grass Sides: trees	none	700
Current conditions	0	1	Front: pavement Back: grass Sides: trees	DX	2500
Add ventilation	*_4_	1	Front: pavement Back: grass Sides: trees	DX	2500
Decrease infiltration	4	*_0.5_	Front: pavement Back: grass Sides: trees	DX	2500
Change surface	4	0.5	*_**Front: grass**_ *_**Back: trees**_ Sides: trees	DX	2500
Replace HVAC	4	0.5	Front: grass Back: trees Sides: trees	*_Fan Coil_	2500

*The alterations in each input file over the original and current conditions are _**highlighted**_

The third simulation added a change of landscape features. The pavement at the entrance was "replaced" with grass, while the grass in the rear was "replaced" by trees. The results were quite similar to the output of the second simulation run (27,817 total annual DDH, and 69.8 kBtu/sq.ft). This minor improvement is due to the fact that the proposed changes were introduced to the narrow elevations of the church, while existing trees that shade the long facades were included in the original input.

The fourth simulation focused on substitution of the existing DX split system with a fan coil system. As in the previous tests, the replacement of the HVAC system was added to the former simulated changes. The normal run examined energy performance and the cost effectiveness of this change. The results showed a small improvement of 2% from the third simulation runs in energy source (from 69.8 to 67.9 kBtu/sq.ft) and a decrease of $5,027 in annual energy consumption. However, the installation of the fan coil system is estimated as $52,135. Thus, it would take the congregation more than 11 years to pay for a new system and would not be cost effective.

Finally, to substantiate the validity of the simulated results, the simulated annual energy consumption of 62,908 kWh was compared with the church's utility records of 62,880 kWh annual use. Also, the simulated annual heat energy of 67.7 MBtu is very close to the real figure of 62.1 MBtu of gas usage, as recorded in the utility bills.

Conclusion

This study applied a structured, systematic approach to the analysis of energy performance in a historic preservation project. This approach included three main phases that utilized computerized energy simulations: analysis of existing thermal conditions of a historic building in its original and current conditions; identification of energy conservation strategies based on this analysis and energy-related design guidelines and preservation briefs; and quantitative and qualitative evaluation of these strategies in relations to historic fabric.

The case study of St. Louis Catholic Church indicated that major improvement in thermal comfort and energy performance can be accomplished through natural ventilation. Reopening the windows eased the discomfort of summer heat and humidity and decreased energy consumption. Such a change is simple, inexpensive, and maintains the historic integrity of the church. This result conforms to energy-design guidelines and preservation standards, which emphasize that the most obvious "inherent" energy-saving strategy is to provide energy-efficient fresh air and light. The computer analysis provided quantitative reinforcement for these recommendations.

The findings demonstrated the sensitivity of the computerized energy simulation in capturing the energy consumption of the existing building and the energy conservation resulting from modifications. This quantitative, computer-based approach was applied to churches in different climates (Geva 1995). In cold climates the simulations identified thermal problems related to cold DDH and heat loads.

Previous studies used this computerized energy simulations to test additional building types, such as historic, vernacular, single-family houses; historic Greek Revival houses; historic house-museums; and fast-food restaurants. The buildings were located in various climates (Geva 1995, 1997, Geva et al. 1997). This research expands the current multidisciplinary approach to historic preservation and widens the scope of computer applications beyond their current use in design and research.

ANAT GEVA is a research fellow in the Historic Resources Imaging Laboratory, College of Architecture, Texas A&M University. Her areas of research are historic preservation and design with climate. Dr. Geva is a registered architect in Israel and an associate member of the AIA.

Notes

1. Barnes (1982) describes the church: "the heavy stone walls seem to rise heavenward with all the faith, and love, and pride of the great Cathedrals of Europe."

2. The ENER-WIN software, a Windows version of ENERCALC simulation program (Degelman 1990, 1991), won a citation in the Progressive Architecture Annual Research Award Program, 1993.

3. ENER-WIN includes an envelope-material catalog and numerous user profiles that are based on ASHRAE 90.1 energy efficiency standards.

4. The weather database of ENER-WIN is based on a statistical summary of thirty years of weather records.

5. Decrement factor is a function of time lag and thermal resistance of a wall. It is used to calculate the derivation of the temperature on the inside surface of a wall, when the heat transfer is derived by a cyclic temperature on the outside surface of the wall (Mackey and Wright 1944).

6. MATERL4 software was developed by Degelman (1978) at Texas A&M University. This program calculates different thermal factors of walls and roofs built of several layers of materials (e.g., construction and finish materials).

7. For thermal properties of walls and roofs see ASHRAE fundamentals book (1985): table 3A, chapter 23. For glazing thermal conditions, see tables 13A, 13C and 32, chapter 27. Data for stained glass was read as indoor shaded glass or tinted glass in these tables.

8. See Al-Homoud (1994) for detailed equations and calculations of DDH.

9. The thermal comfort zone as defined by ASHRAE ranges between 68° and 79°F. For a graphic illustration of the deviation of a building's internal conditions from the comfort zone, see Fig. 3.2 in Al-Homoud (1994).

10. Source energy: energy consumed by the power plant to produce the total energy used by the building.

11. The energy values obtained for the church are better than the BEPS (building energy performance standard) for this type of building in San Antonio (167 kBtu/sq.ft.).

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