# The use of computerized energy simulations in assessing thermal comfort and energy performance of historic buildings

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## Abstract

The balance between preservation objectives and the thermal needs of an historic structure is addressed in different publications that integrate the general recommendations of 'design with climate' with specific guidelines set forth by the US Secretary of Interior's Standards and Guidelines for Rehabilitation of Historic Buildings. These accepted recommendations serve as the basis for morphological qualitative analyses of thermal comfort of historic buildings. To augment these analyses, this paper introduces a systematic quantitative approach to determine the energy needs of these buildings and to develop energy conservation strategies in their retrofitting. Using a computerized energy simulation program the study proceeds in three major steps: (a) evaluation of the thermal comfort and energy performance of the target building in its original historic and its current conditions; (b) development of energy strategies to improve thermal conditions in the historic building, while maintaining the building's historic integrity; and (c) evaluation of these strategies. This paper demonstrates the utility of ENER-WIN – an hour by hour energy simulation program in testing thermal comfort and energy performance of three historic buildings: the 1868 St. Louis Catholic Church in Castroville, Texas, USA; Frank Lloyd Wright's 1905 Unity Temple in Oak Park, Illinois, USA; and a 1936 Bauhaus Apartment Building in Tel Aviv, Israel.
*Keywords: energy simulations; thermal comfort; energy conservation strategies; historic buildings.*

## 1 Introduction

The balance between preservation objectives and thermal needs of a historic structure is addressed in different publications that integrate the general recommendations of 'design with climate' with specific guidelines set forth by the US Secretary of Interior's Standards and Guidelines for Rehabilitation of Historic Buildings [1].

The general design guidelines and architectural strategies that were developed to accomplish thermal comfort in the design of buildings in different climate zones usually refer to site layout, building form, construction and finish materials, and architectural details [2]. A greater climatic comfort can be achieved in a building that fulfils most of the design strategies for the specific climate.

The specific guidelines for achieving thermal comfort in historic buildings consider the general recommendations and focus on the importance of the inherent energy savings characteristics of historic buildings. They suggest passive and retrofitting measures to conserve energy (e.g., walls and roof insulation, natural ventilation, air infiltration), and how to incorporate mechanical systems in these buildings [3]. Moreover, the US Secretary of Interior's Standards and Guidelines for Rehabilitation of Historic Buildings include *special requirements for energy efficiency*.

These accepted recommendations serve as the basis for morphological qualitative analyses of thermal comfort of historic buildings, as well as a list of "to do" and "not to do" in terms of energy requirements for such buildings. To augment these analyses, the objective of this paper is to introduce a systematic quantitative approach in the form of computerized energy simulations. The study introduces this rigorous methodology within a suggested framework of three main stages: (a) evaluation of the thermal comfort and energy performance of the target building in its original historic and current conditions. This step uncovers the inherent energy components of the building and illustrates the impact of the modifications that the building underwent over time on its comfort level; (b) identification of energy conservation strategies based on the simulation results that point out the areas for thermal improvement, while maintaining the building's historic integrity; and (c) evaluation of these strategies.

The paper demonstrates the application of ENER-WIN [4] – a computerized energy simulation program for testing thermal comfort and energy performance of three case studies: 1868 St. Louis Catholic Church in Castroville, Texas, USA; Frank Lloyd Wright's 1905 Unity Temple in Oak Park, Illinois, USA; and a 1936 Bauhaus Apartment Building in Tel Aviv, Israel. These buildings were selected since they were built in different periods of time, in various locations (climate regions), are recognized as significant historic buildings/sites [5], and were all preserved to continue and serve in their original function. However, the implications of this research apply to other historic buildings in different climatic regions.

## 2 Research instrument

This study used ENER-WIN [6] to assess the thermal comfort and energy performance of the three targeted buildings. ENER-WIN performs an hour-by-hour energy simulation based on given climatic conditions, building description, and economic data. The coding of an input file of this program utilizes the software's weather database (30-year statistics) of more than 1000 cities worldwide, a catalog of envelope materials and windows properties, Heating Ventilation, Air Condition (HVAC) zones, wall surfaces/orientations/ shading conditions, and up to 50 user-defined profiles based on ASHREA energy efficiency standards.

The program's output includes zonal and building calculations of loads created by passive and active systems and energy use.

Two modes of the ENER-WIN program are used in this study. First, the *passive system* to evaluate the comfort level of the passively heated and cooled buildings. This mode applies mainly to structures without HVAC. The output of these simulations represents the deviation of the internal conditions of the building from the designated comfort conditions. To assess the comfort or discomfort of these internal conditions, the simulation provides a summary of total operative temperatures expressed by the total Discomfort Degree Hours (DDH) [7]. This output implies an inverse relation between the DDH and the compatibility of the building to the local climate. In addition, the results of the simulation show a percentage of total comfort (between 68°F - 79°F) and discomfort (too hot- more than 79°F and too cold- less than 68°F) occupancy hours.

The second run, the *active system* assesses the energy performance of a building with an HVAC system in energy units and dollars. This run can simulate historic buildings *as if* they include HVAC. The results of these simulations show the building's source energy in thousand Btus per square feet (kBtu/sq.ft.) [8], energy loads in million Btus (MBtus) [9], and energy cost analyses. The results detail monthly and annual heating and cooling loads, peak loads, and energy-demand profiles [10]. The more Btus required maintaining thermal comfort, the less compatible the building is to the climate. In addition, this simulation identifies the areas for thermal improvement by providing percentage breakdowns for heating and cooling energy expenditures for a number of building components.

## 3 Background of the project's buildings

The information on the project's buildings was obtained from literature review; field trips; archives (such as the Frank Lloyd Wright Taliesin West Archive, the Archive of Tel Aviv municipality); 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.

### 3.1 St. Louis Catholic Church, Castroville, Texas, USA

In 1844, immigrants from Alsace, France built their first St. Louis Catholic Church in Castroville, Texas as a tiny chapel. In 1868, the current church was built near the chapel as a gothic-style church to resemble the churches in their homeland: "the heavy stone walls seem to rise heavenward with all the faith, and love, and pride of the great Cathedrals of Europe" [11].

The church is a single rectangular nave in a plan of 156 by 50 feet, one story high, and built with thick local limestone walls, plastered inside. The double pitched roof is covered with wooden shingles. It has a pitched arched ceiling with exposed wooden roof trusses. The church's 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.

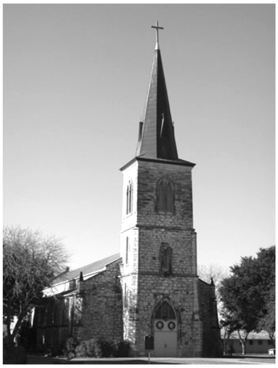

Figure 1: St. Louis Catholic Church, Castroville, Texas.

### 3.2 Unity Temple, Oak Park, Illinois, USA

Unity Temple was designed by Frank Lloyd Wright in 1905 in Oak Park, Illinois. It is a complex of three buildings that are spread along a 142 feet main axis from north to south, Fig. 2.

The main building on the North is the Temple. It is a cube of 64'-0" in plan and 47'-0" in height. It includes an auditorium with three open galleries, a space for the organ on the fourth side, and a lower floor for storage and restrooms. The second building of the complex is the Unity House, located on the south, and measures as a rectangle of 91'-6" by 50'-0 in plan, with a height of 30'-0". It includes a main gathering/reception hall, open classrooms on both sides of the upper level of the hall, and a kitchen separated from the hall by a huge chimney. The third building is a two story, 30'-0" long, 24'-0" wide, foyer/entrance that connects the Temple with the House. Its lower floor opens to an entrance plaza on the west, and to a courtyard on the east. The pastor office is located in its upper floor.

Unity Temple was constructed with 'thoroughbred' reinforced concrete. Its double roof consists of broadly projected concrete slab roofs that are penetrated by a grid of a glass ceiling and covered by a sloped skylight roof, which is screened from the street by a parapet. Leaded amber glass with a simple geometrical design decorates the windows and glass ceilings. Inside, the walls are stippled plaster [12].

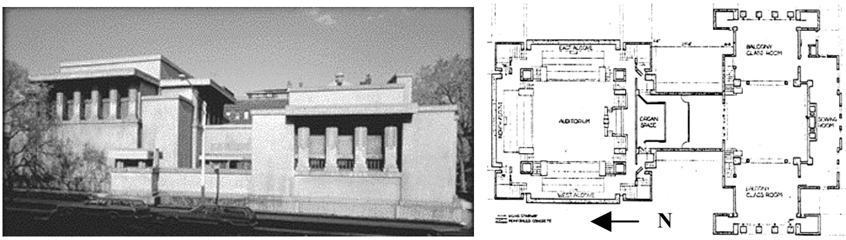


Figure 2: Unity Temple, Oak Park, Illinois.

### 3.3 Max Libling Bauhaus apartment building, Tel Aviv, Israel

The Max Libling Apartment Building was built in 1936 in Tel Aviv, Israel and was designed by Dov Karmi (1905-1962). It is considered a typical Bauhaus apartment building in Tel Aviv with its deep horizontal balconies that resemble the ribbon windows of the European International Style, Fig. 3.

The building is three stories high with a typical floor plan of 2347 sq. ft. on each level. Each floor includes two apartments of four rooms, a kitchen, and one and a half bathrooms. All rooms in every apartment open to an interior hall/corridor that is linked to the apartment's entrance and have at least one window or door to the deep horizontal balconies. The roof of the building is flat and includes a common service room that is visible only from the side of the building. The entrance of the building includes a shaded long wooden pergola that starts at the street level with a concrete beam and is surrounded with plants. The building was built from silicate concrete blocks, stuccoed and washed white in and out.

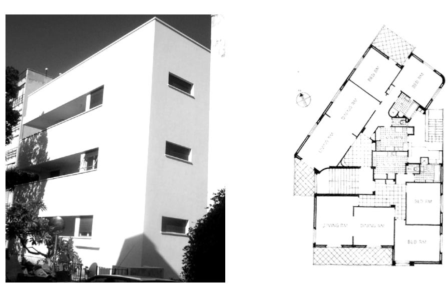

Figure 3: Max Libling Building, Tel Aviv, Israel.

## 4 Research stages and results

The paper demonstrates the application of ENER-WIN by running its two modes of simulations (active and passive) on the three buildings. Two input files were prepared for each of the buildings: one describes the building's original conditions; the second includes information on subsequent changes and the current conditions. Following the simulation runs, energy conservation strategies were identified and a third input file was prepared to evaluate these strategies.

### 4.1 Thermal comfort and energy performance of the original historic buildings and their modified conditions

The results of the simulations that were conducted on the three buildings in their original conditions uncover their inherent climatic qualities and reveal that the design/construction of these historic buildings was environmentally conscious. The output of their annual source energy is better than the BEPS (Building Energy Performance Standard) for their type of building (e.g. church, house) in each respective location. Thus, the energy performance of these buildings can be acceptable even by today's standards. Yet, the energy inherent components were seldomly abused by changes the buildings underwent through the years. Changes included closing and sealing of openings due to installation of HVAC systems, which blocked the natural cross ventilation; replacement of the surroundings surfaces from vegetation to pavement, which increased sun reflection onto the building; and changes in the number of people using the facility, which contributes to changes in the heat gain of the building.

The results of the simulations runs on the original St. Louis Church show a discomfort level of 39,923 total annual DDH, while in the modified Church the discomfort increases to 65,975 DDH. This increase is mainly expressed in the summer (from 8,959 hot DDH to 47,856 hot DDH). With the installation of a HVAC system, the Church consumes an annual source energy of 95.2 kBtu/sq.ft with a total annual cooling load of 473.2 MBtu and an annual heating load of 67.7 MBtu. These values demonstrate the major impact of the Texas summers on the thermal comfort of the building.

The summer season of Tel Aviv is the most demanding period in terms of thermal comfort. Therefore, the simulations were conducted on the building for the months of June, July, and August. The thermal discomfort of the original design of the Bauhaus apartment building in the summer is 163 DDH for that period, while in the modified building the discomfort increases to 2018 DDH. The results also show that in its original form, the building was comfortable during 90% of the summer occupied hours. It was too hot in the building only during 8% of these hours. In contrast, in the modified building only 66% of the occupied hours were comfortable and 34% were too hot. If the original building would have an HVAC system it would have consumed only 7.4 kBtu/sq.ft source energy and less than 18 cooling MBtus. With the installation of the AC window/wall units, the building doubles the source energy consumption and uses 82 cooling MBtus, which is almost five times more cooling load than the original.

Since Unity Temple did not undergo major changes during the years, I only report the results of the simulations of the original conditions of the Temple. The results of the passive run showed 62,882 annual DDH. Most of this climatic discomfort can be attributed to the cold weather of Oak Park (62,537 DDH-Cold vs. 345 DDH-Hot). In addition, it shows that the Temple is comfortable during 46% of the annual occupancy hours. It is too cold in the building during 53% of the annual occupancy hours, and too hot only in 1% of the annual occupancy hours. The active run analyzed Unity Temple *as if* it had a HVAC system. The results show an annual source energy of 129.6 kBtu/sq.ft., which is better than the BEPS (141 kBtu/sq.ft.) [13], with annual heat loads of 951.43 MBtu, and annual cooling loads of 125.58 MBtu. These results parallel the findings of the annual cold and hot DDH and demonstrate the major impact of Chicago's cold winters on the building's thermal conditions. The findings can also support an assumption that for the cold conditions Frank Lloyd Wright relied on his introduction of an active heating system into the Temple rather than developing effective passive heating systems [13, 14].

### 4.2 Identifying energy conservation strategies

The active simulations of the historic buildings not only evaluate the thermal comfort and energy performance of the buildings in their different stages, but also point out areas for thermal improvement. Energy strategies have been developed to treat the elements that contribute significantly to the cooling/heating loads. These treatments were analyzed in accordance with preservation objectives and guidelines [3, 1].

The analysis of the active simulations of St. Louis Church yield four energy conservation strategies: reopen the windows when weather permits to allow natural ventilation in the church as means to reduce the energy consumption and decrease condensation; decrease the infiltration rate when the HVAC operates by adding simple weathering measures to the openings; change the surface exposure adjacent to the walls with landscape features; and replace the existing HVAC system with a more efficient one [15]. It should be noted that the insulation of the walls and roof was also considered, yet this treatment would have damaged the church's historic integrity.

The major contributor to the cooling loads in Unity Temple is the solar heat that radiates through the windows (124.2 MBtu). However, the thermal mass effect of the concrete walls decreases the cooling load by 146.22 MBtu, thus, neutralizing the solar effect. The major contributors to the heating loads in the church are the roof (724.5 MBtu), exterior walls (524.6 MBtu), and infiltration/ventilation (292.77 MBtu). These results suggest that the deficiency of insulation and weathering materials causes the building to be thermally less comfortable in the winter than in the summer. Thus, it is suggested to use simple inexpensive measures, such as weathering the windows and adding insulation to the roof to improve the thermal comfort and energy performance of the building while maintaining its historic integrity.

The initiative to preserve the Bauhaus apartment building in Tel Aviv to resemble the original design from the 1930's not only restored the historical integrity of the building, but also rediscovered the energy inherent component of the original building. The actual preservation work in the late 1990's included the following treatments: reopening the balconies to allow natural ventilation to the building as well as to shade the walls and windows facing the balconies; repairs of the building's surface and roof and applying new stucco with a white washed finish that helped to reflect the sun and reduce some of the heat gain;

replacing the air condition window/wall units with a central system that allows re-using the open floor plan of the apartment. This in turn provides airflow and natural ventilation when windows are open; and weathering the windows in such a way that enables to open them when weather permits (mainly during summer nights).

### 4.3 Evaluation of the identified energy conservation strategies

The energy conservation strategies that are described above were tested using ENER-WIN. The suggested improvements were coded into the input files of the buildings and the passive and active modes of simulations were run on each of the case studies. In all cases the results showed that simple and inexpensive measures can improve the thermal comfort and energy performance of the buildings. It should be noted that the computerized energy simulations can be utilized not only in an additive way to examine the impact of all recommendations on the buildings' performance, but also to test each strategy by itself to demonstrate its effective impact on the building's thermal comfort and energy performance [15].

Introducing all four energy strategies (natural ventilation rate 4cfm/sq.ft; infiltration 0.5 ACH; trees and grass instead of pavement; replacement of the DX HVAC system with a Fan Coil unit) into St. Louis Church leads to an improvement in thermal comfort of 30% over the original conditions and 58% over the modified church. The church's source energy performance lowers by 27% from 95.2 to 67.9 kBtu/sq.ft.

The energy conservation strategies for Unity Temple were simulated with an insulated roof (U-Factor of 0.069), and a reduced infiltration rate of 1.0 ACH. The results of the passive and active simulations show an improvement in thermal comfort of 9%, and in energy consumption of 20%.

The simulations on the preserved Bauhaus apartment building show similar levels in the summer thermal comfort to the original design. The use of the energy inherent components of the building (natural ventilation 4cfm/sq.ft; infiltration to 0.3 ACH; windows' shading coefficient 0.1; shaded walls' U-Factor 0.23; adding shades in front and above the walls and openings facing the balconies) with an efficient central AC brought the level of comfort to 90% of the summer occupancy hours and the consumption of 7.2 Kbtu/sq.ft source energy and less than 17 cooling MBtus which is slightly better than the original.

## 5 Conclusion

Although ENER-WIN was developed to assess the thermal comfort and energy performance of new designs, this study demonstrated the application of this rigorous methodology in testing and evaluating the climatic conditions of historic buildings. The study illustrates that this quantitative and systematic approach may uncover inherent thermal qualities and help to identify and evaluate energy conservation strategies in retrofitting these buildings while maintaining their historic integrity.

The study's findings are in line with the recommendations based on the integration of the general guidelines of 'design with climate' with the responsible preservation objectives as set forth in guidelines for energy conservation in historic buildings, and in the Technical Preservation Briefs. Moreover, these results conform to current studies that emphasize the effectiveness of the combination of the building's architectural component (passive heating and cooling system) with efficient mechanical systems [16].

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