NATURAL VENTILATION IN HISTORIC BUILDINGS: THE KALTEYER HOUSE IN SAN ANTONIO, TEXAS. ANALYSIS AND SIMULATIONS OF NATURAL VENTILATION

Eleonora Laurini[2], Angela Lombardi[1], Hazem Rashed-Ali[1], Pierluigi De Berardinis[2], Simonetta Cirrana[2], John Murphy[1], Michael Carroll[1]

[1]University of Texas at San Antonio, San Antonio, Texas
[2]Universita' degli Studi dell'Aquila, Italy

ABSTRACT: Approximately one-fifth of the planet's geographical area is characterized by hot-humid climates, while being inhabited by one-third of the total world population. The majority of continental areas have weather conditions outside the thermal comfort zone. This has resulted in considerable and consistent increases in the use of HVAC mechanical systems, with its associated energy costs and environmental impacts, which potentially nullify the benefits otherwise achieved by the energy conservation policies implemented by many industrialized countries.

Much can be learned from the study of historical buildings where sensitive design approaches were implemented with respect to natural ventilation strategies. An excellent example of a passive stack effect design employing skylights to take advantage of convective air flow is found in the Kalteyer House located in San Antonio, Texas. San Antonio is situated in Climate Zone 2A, hot-humid. The house under analysis is a three-story plus basement, single-family brick residence, designed at the end of the nineteenth century in Richardsonian Romanesque style by the architect James Riely Gordon (1863-1937). Here, the difference in temperature and pressure between two different zones of the house, enhanced by the presence of the skylight, creates naturally occurring convection air flows without the aid of mechanical systems. Natural ventilation can be an incredible resource for implementing passive cooling of buildings.

This paper aims to investigate how to maximize the potential offered by these passive design strategies by developing an understanding of how they have been historically implemented, specifically in the Kalteyer House, and then exploring their potential as a valid alternative for achieving thermal comfort in newly-designed residential buildings. The effectiveness of this passive-cooling strategy is determined through an in-depth case study analysis and critical understanding of the passive system designed by James Riely Gordon, evaluated through CFD software simulations to determine how to maximize the potential of stack ventilation, which is currently underutilized due to the advent of mechanical-cooling systems. The goal of the analysis is to achieve the best performance in terms of thermal comfort with the minimum amount of energy consumption, thus reducing the resulting environmental impact.

KEYWORDS: Kalteyer House, historic buildings, natural ventilation, hot-humid climate, software simulation

INTRODUCTION

Approximately one-fifth of the planet's geographical area is characterized by hot-humid climates, while being inhabited by one-third of the total world population. The majority of continental areas have climate conditions outside the comfort zone. This has resulted in considerable and consistent increases in the use of heating, ventilating, and air conditioning (HVAC) systems, as well as their associated energy costs and environmental impact, potentially nullifying the benefits otherwise produced by energy-conservation policies implemented by many industrialized countries.

Much can be learned from the study of historical buildings where sensitive design approaches were implemented with respect to ventilation devices, such as passive stack effect convection-related air flow employing skylights, a method utilized in the 1892 Kalteyer House located in San Antonio, Texas, designed by the architect James Riely Gordon (1863-1937), renowned for his design of numerous courthouses across the nation.

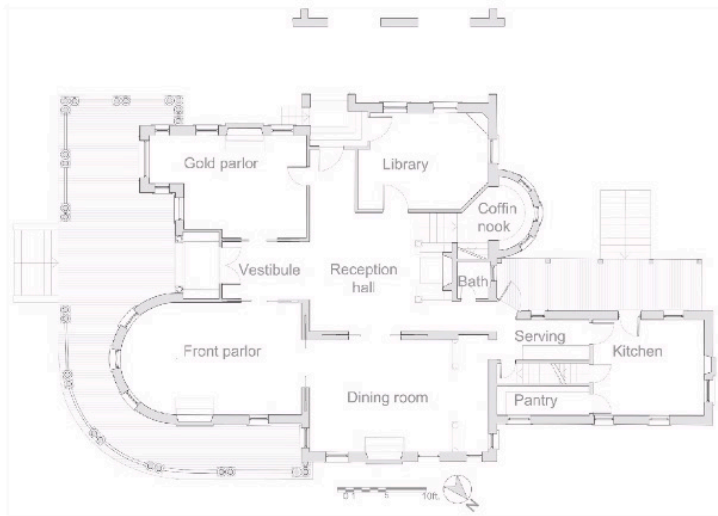
This paper will report on and identify lessons learned from an interdisciplinary project aiming at identifying low retrofit for historic architecture in Texas, built prior to the introduction of mechanical systems. The project is involving researchers from architecture history, historic preservation and sustainability and aims to identify sustainable strategies adopted in historic buildings in order to utilize them to implement cost effective retrofit strategies for energy use reduction, while enhancing the unique typological and construction features of historic structures.

The architect James Riley Gordon specifically addressed the design challenges of the Southern climate in his courthouse and capitol building projects. In his technical correspondence, Gordon writes: "It is not difficult in the South to keep comfortably warm during the winter, but it is a monster problem to keep cool during the long hot summer" (Gordon, 1890-1937). Not as well known is that his stack-effect design was also used in other building typologies, such as the residence under analysis. The case study under analysis, the Kalteyer House, may have been a proving ground for the architect's climate-responsive design ideas, leading to the development of a new, more sophisticated courthouse typology, such as the one Gordon proposed for Brazoria County in 1894.

This study investigates, through CFD software simulations, the passive-cooling design features of the Kalteyer House with the objective of verifying their effectiveness. This design is characterized by a ventilating shaft corresponding to the entrance hall which utilizes passive stack effect convection-related air flow.

1.0 BRIEF OVERVIEW OF THE KALTEYER HOUSE HISTORY

The Kalteyer House is a three-story, single-family brick residence, designed in 1892 in the Richardsonian Romanesque style by the renowned architect James Riely Gordon (1863-1937). It is located in the King William Historic District, one mile southwest of the Alamo, in the city of San Antonio, Texas.



Figures 1, 2: The Kalteyer House in 2016. Source: (Author, 2016) and the house's first floor plan (Author, 2016)

Design and construction of the house was commissioned by George Kalteyer for his family. George Kalteyer (1849-1897) was one of the city's most successful businessmen in the final two decades of the nineteenth century, during which the city of San Antonio witnessed a tremendous growth and a thriving economy, largely due to the introduction of the railroad to the city in 1877. The King William neighborhood was a logical location for the wealthy son of German immigrants to choose for a homestead.

The neighborhood, in fact, was named between 1868 and 1873 in honor of Wilhelm I of Prussia. (Burkholder et al., 1973); still sparsely populated in 1873 (1873 Augustus Koch's *Bird's-eye View of San Antonio*), in few years it transitioned to an aristocratic community (1887 Augustus Koch's *Bird's-eye View of San Antonio*). Large, multi-story, masonry houses appeared, beginning along the river-side of King William Street. An eclectic array of architectural styles were employed, typical of this revivalist period. Known for its large population of successful German immigrants, the King William neighborhood soon became San Antonio's most exclusive suburb.

For his new home at 425 King William Street, Kalteyer had the choice of a handful of architects who were working in San Antonio near the end of the nineteenth century. Kalteyer chose James Riely Gordon who in 1892 was beginning to eclipse also the city's most prominent architect, Alfred Giles. During the same period that he was designing the Kalteyer House, Gordon was also working on two of his landmark commissions: the Texas Pavilion at the Columbian Exposition in Chicago and the Bexar County Courthouse in San Antonio (Meister, 2011) He had already designed several courthouses around Texas, which are also part of this research project.

Between 1830s' and 1870s', domestic architecture becomes a central focus both in the 'quest' of an American identity and for the development of main cities. The stylistic and decorative research characterizing such process certainly finds an important reference in the work of Henry Hobson Richardson (1838-1886) who introduces in American architecture the Romanesque style. This style, however, is not intended as an imported style, but as a 'composition method', which takes in consideration construction features, drastically reducing decoration to the essential. (O'Gorman, 1987)

In the Kalteyer house, the reference to Richardson style is evident both in the use of masonry masses made of stone and brick, interrupted by arches, towers and wide roofs, and in the use of architectural forms associated with typological and technological innovations, such as indoor ventilation system shaping the home's interior layout.
The house is characterized by a combination between the authority of classical order and the dynamicity of the asymmetric form of the main façade, expressed by the volumetric masses' variation on the upper level. The authority of classical order is expressed through the use of binate columns and tympanum crowning the entrance, the asymmetric form is developed both in plan and in the elevation of the main façade, where a large conical tower is anchoring the east corner, and a slender octagonal belvedere marks the opposite side. Polychromatic voussoirs of white limestone and red sandstone, set against the yellow brick walls, create a dynamic and dramatic contrast between materials, volumes, solids, and voids.

This combination of classical and dynamic forms intimately ties the work of Gordon to the one developed by the 'masters' of American architecture, such as Richardson, Sullivan and the early works of Wright.
The house, beyond its stylistic features, incorporates original elements of the architect's design philosophy, including attention to light, structural design, and mechanical systems, including heating and anti-burglar systems, considered at that time the most technologically-advanced.

As the twentieth century progressed, and the original residents of the King William neighborhood passed away, many of the homes, including the Kalteyer house, were converted to low-income apartment buildings. Following designation of the King William neighborhood as a historic district by the City of San Antonio in 1967 and as a National Register Historic District in 1972, numerous houses were returned to their former splendor, and King William Street once again became a fashionable address. The Kalteyer House was restored with attentive philological attention by Mr. Sidney Francis in the 70s.

2.0 TOWARD A NEW UNDERSTANDING OF HISTORIC BUILDINGS

2.1. The building as a 'direct source'

The study of 'indirect sources' should be intersected with the analysis of 'direct sources', the latter represented by the structure itself, in order to achieve a critical understanding of the unique building's feature and its potentials.
Indirect sources include bibliographical and archival research, comparative analysis of building typologies, decorative elements and construction technique, briefly presented in the previous chapter. (Morbidelli et al, 2012). The consultation of primary sources, ie. the archival documents in the Alexander Archive in Austin, Texas, allowed the team to bring new light on the architect's main design interests, through his writing. The building, as a 'direct source', provides 'intrinsic data', meaning all possible information that the structure may display (De Angelis d'Ossat, 1995), in this case specifically focused on climate-responsive strategies utilized by Gordon.
This phase included the following activities:

1) An architectural survey of the building: floor plan, sections and elevations were recreated, using as a starting point archival drawings (Gordon, Alexander Archive) which were drafted in the 70s, after the house complete restoration. These drawings, never completed, were made by architecture students as a training for HABS drawings execution. New measurements were taken with a disto Laser Leika, integrated with tape measures.

2) A visual inspection: this activity focused on the identification the relevant building features where climate responsive strategies were applied, such as orientation, openings, shading devises, construction techniques, etc., and lack of major prior retrofits. A description of the passive design characteristics is included in Table 1. The inspection also aimed to identify major energy efficiency problems or deficiencies including presently major energy-consuming systems such as HVAC, as well as potential issues in the building envelope.

Table 1: Passive cooling techniques used in Kalteyer house

THERMAL MASS	Load bearing masonry brick walls. Wall thickness: from 12 inches to 16 inches. The thermal mass results in a summer lag time that improves thermal comfort in the afternoon.
STACK VENTILATION	Entrance hall performs the function of a ventilating shaft, with a skylight composed of two openable windows. This is supplemented by window openings from the side rooms, connected to the central shafts through transom windows.
CROSS VENTILATION	On first and second floor, doors around the central ventilating shaft are aligned. Transom windows on each door ensure cross ventilation even when doors are closed.
HIGH CEILING	High ceilings allow for air stratification. Ceiling height for first and second floor: 11 feet and 6 inches

EARTH COOLING	Building is elevated on a basement, partially underground. This earth coupling provides cooling in summer and warmth in winter.
SHADING	Façade is wrapped by a deep porch providing full protection from the south sun, and partial protection from east and west sun.

2.2. Review of relevant literature

Existing residential buildings are conventionally considered less energy-efficient than new structures, since they were erected before energy-efficient standards were imposed. Some leading national and international organizations in North America and Europe have become engaged with their governments on the debate on how historic structures can be considered more sustainable, overall, than new constructions. The English Heritage was one of the first organization to claim that some historic structures are inherently climate responsive, utilizing specific construction techniques and materials, like in the case of "many vernacular styles that have massive solar gains, thick walls and small windows" (Berthel-Bouchier, 2013, p. 139).

Therefore, performances of historic buildings can be improved also through a deeper understanding of how historic structures are inherently climate responsive, in the effort to fit the precise standards for evaluating energy efficiency and carbon footprint, such as the ones provided by the U.S. Green Buildings Council's Leadership in Energy and Environmental Design (LEED) (Berthel-Bouchier, 2013).

For different climate regions, several studies have been conducted on identifying appropriate retrofit strategies for existing housing (e.g. Florian et al. 2011, Parker 2001, Burgett et al. 2013), while very few focused on the analysis of passive design characteristics of historic homes despite their historical, cultural and social significance, both in hot and humid climate (Rashed-Ali et al., 2015; Dupont, 2016) and hot dry climate.

In cases of hot and humid climates, available studies focus on contemporary homes, investigating retrofit potentials through the installation of radiant barriers such as the one conducted by the Florida Solar Energy Center (Parker et al. 2001), or the one by Pacific Northwest National Laboratory, PNNL, the latter covering a high number of case studies (51 homes in total) located in marine, cold and hot-humid climates which also included three homes in San Antonio (Chandra et al. 2012).

A simulation-based approach was adopted by Burgett et al. (2013) to identify retrofit packages for existing homes in hot and humid climates in general.
In this context, the analysis of integrated climate responsive strategies in historic homes is a clear addition to the current effort of improving energy performance both of historic and contemporary house stock.

3.0 CLIMATIC CHARACTERISTICS OF THE CITY OF SAN ANTONIO, TEXAS

The city of San Antonio, Texas, is characterized by hot humid climate. The eastern third of Texas has a Subtropical Humid climate that is mostly typified by warm summers, the central third of Texas, where San Antonio is located, has a Subtropical Sub humid climate characterized by hot summers and dry winters. The variation of climate types in Texas is caused by the physical influences of the State being located (1) downwind from mountain ranges to the west, (2) proximate to the Gulf of Mexico and the southern Great Plains, (3) west of the center of the Bermuda high pressure cell, (4) at relatively a low latitude, and by (5) the transitions in land elevation from the high plains and mountains to the coastal plains. These influences on the weather particularly affect the moisture content of the air-define climate. (Larking and Bomar, 1983, p. 3)

Average relative humidity in San Antonio is higher than 50% all year long, with peaks of 70%. Therefore, perceived temperature is far outside the comfort zone. According to ASHRAE Standard 55, comfort temperature, measured at dry bulb, must be within 68°F (20°C) e i 78°F (25°C), with relative humidity between 40-80%. Despite this, an analysis of the San Antonio Climate shows that a strong potential exists for achieving thermal comfort in significant portions of the year using natural ventilation. Figure three shows a monthly temperature range distribution compared to the adaptive comfort range for the city, in which we can see that average daily temperature fall mostly within and around the comfort zone in the summer months.

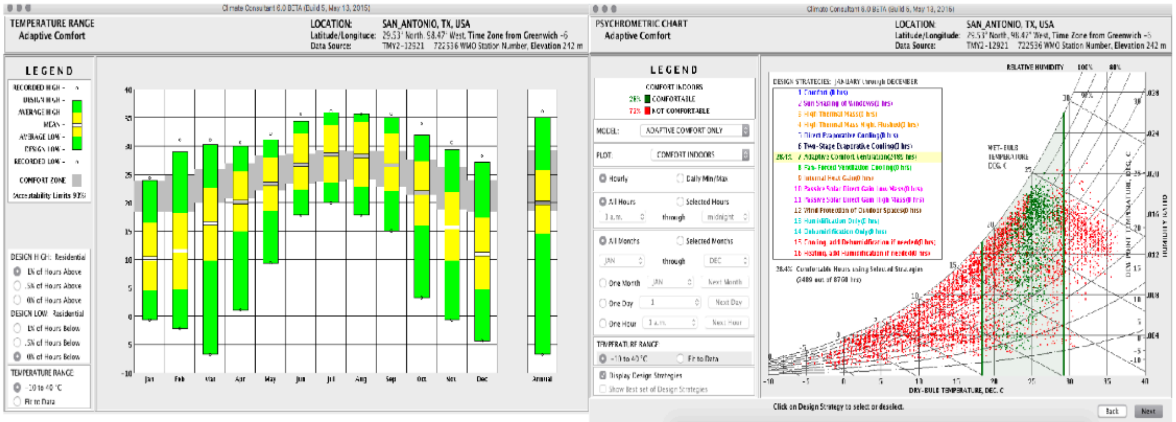


Figure 3,4: Monthly temperature range compared to comfort range using the adaptive comfort model in San Antonio, and an assessment of the potential of adaptive comfort cooling in the same climate.

Figure 4 also shows an analysis of the potential of adaptive comfort ventilation using the Climate Consultant, which shows that this strategy can achieve thermal comfort on 78% of the hours of the year. This, combined with the somewhat strong south east prevailing wind direction especially indicates the good potential offered by ventilation in this climate.

4.0 STACK VENTILATION IN THE KALTEYER HOUSE'S ENTRANCE HALL

The Kalteyer House incorporates climate-responsive design principles that the architect was experimenting and applying in the several Texas courthouses which he designed and built from 1888 to 1892, such as the one of Aransas county (demolished), Fayette, Erath and Victoria counties (Meister, 2011). In these projects he developed buildings constructed of solid masonry which incorporated "ventilating shafts and tower combined" in the center of the building (Gordon's Affidavit in Meister, 2011, p. 290-291). In the architect's correspondence, we learn that Gordon believed "The greatest consideration should be given in our mild climate to ventilation;" therefore buildings can be "especially designed with reference to its peculiar fitness for this climate" (Gordon, 1890-1937, AAA).

The floorplan of the Kalteyer House is a centrally-organized typology developed around the entrance hall and elevated upon a brick foundation incorporating a basement. The entrance hall performs the function of a ventilating shaft, similar to those which Gordon created in his courthouses. From this space the main stairwell leads to two upper floors. At each level, a distribution space serves the rooms. Doors around the central ventilating shaft are characterized by the presence of colored-glass transoms which open to take advantage of cross ventilation.

Figure 5: Images from the Kalteyer House: Ventilated shaft is surrounded by the stairwell leading to upper floors; the skylight has the dual role of illuminating the space and creating convective air flows. Source: (Author, 2016)

The entrance hall lies beneath a large, stained-glass, operable skylight, which not only brings light into the space, but also expels the rising air, thus preventing overheating in the attic space “between the top story ceiling and the roof thoroughly ventilated” (Gordon, Alexander Archive). Such a system is “preventing any accumulation of hot air and rendering the top story apartment as comfortable as those of the other stories” (Gordon, 1890-1937, AAA). The stack-ventilation effect relies on convection and occurs when cool air enters a home on the first floor or basement, absorbs heat in the room, rises, and exits through upstairs openings. Pressure differences, in fact, create convection air flows, producing a partial vacuum, which pulls more air in through lower-level windows. This effect works efficiently in open-air designs with operable skylights, as applied in the house under analysis, or also with windows such as clerestories located near the top of the space. Gordon describes the central space designed for one of his courthouses as follows:

> “[it] acts upon the same principle as a fire place with good draft, that some of you have probably noticed draw a piece of paper up the chimney, except this is larger scale and during period that there is no breeze, by opening the outside windows and transoms, and opening some windows as much as little circulation of air can be created as is desirable….” (Gordon, 1890-1937, AAA).

Gordon also explains that:

> “This shaft can be made to draw thousands of cubic feet of air per minute from the outside of the building through these chambers as up this shaft…. This is not an experiment as the many letters from those who have occupied the completed buildings embodying this system will testify. This is the most practical, simple, effective and inexpensive system of ventilation” (Gordon, 1890-1937, AAA).

Figure 6 shows a section through the house which illustrates how the ventilated shaft is surrounded by stairwell leading to upper floors, the skylight has the dual role of illuminating the space and creating convective air flows.

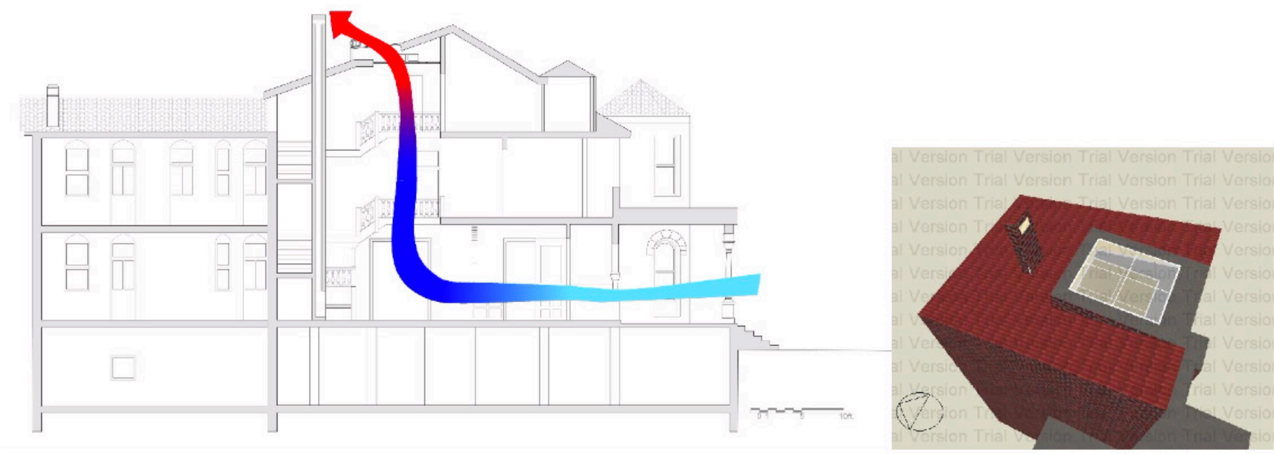


Figure 6 and 7: Diagrammatic section through the Kalteyer house (Author, 2016) and the Design Builder whole building performance model.

5.0 CFD SIMULATION OF NATURAL VENTILATION

5.1. Software Simulations and Proposed Configurations

To test the effectiveness of the natural ventilation design solution in the Kalteyer House, a whole building simulation model was created for the house in the Design Builder Software (see Figure 7). The CFD module in Design Builder was then used to simulate the comfort conditions in the central space in the house using several configurations representing different scenarios for the use of the shaft and side openings. In total seven configurations were simulated. A brief description of these configurations is included in Table 1.

Table 1: Description of the CFD simulation configuration performed using Design Builder.

Configuration Number	*Configuration Description*
Configuration 1	Baseline configuration, both fireplace and skylight are closed. No air flow.
Configuration 2	Only skylight open, no major airflow expected due to lack of inlets.
Configuration 3	Both skylight and main entrance open. Entrance provides cool air inlet while warm air is exhausted through skylight.
Configuration 4	Both skylight and main door open. Chimney open and assumed to work as a solar chimney acting as a second inlet.
Configuration 5	Both skylight and main door open. Side entrance is also open to take advantage of cross ventilation perpendicular to the plane of the door/skylight (see plan in figure 2).
Configuration 6	Same as configuration 5 plus opening the chimney,
Configuration 7	Same as configuration 5 plus opening a window on the first-floor level to test the impact of air flow from higher levels.

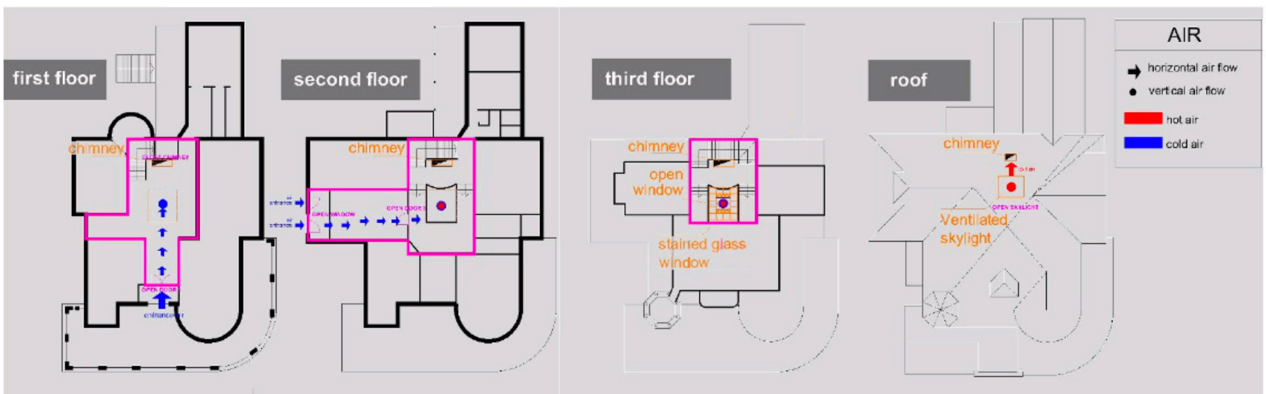


Figure 8: Diagram of air flows generated on each floor to create Configuration 7, the one showing best simulation results (Author, 2017)

The simulation was only conducted in the affected rooms including the central shaft space, the stairwell, and the first-floor rooms. The dependent variables generated from the CFD simulation included relative humidity, air temperature, radiant temperature, operative temperature and dry bulb temperature. Operative temperature is the temperature perceived by the occupants.

The simulation was conducted for representative days in the summer months (June, July, and August), and the dependent variables were calculated at the levels of the ground floor, third floor, and the attic (skylight cavity), which represent the spaces most affected by the influence of air flow. Air speed was assumed to be zero for configuration 1 and between 20 – 40 fpm for the other configurations.

5.2. Analysis of results

The summary of the simulation results for all configuration is included in Table 2.
Table 3 shows an analysis of thermal comfort parameters under the conditions generated from each simulation generated using UC Berkeley's Center for the Built Environment (CBE) online Thermal Comfort Tool conducted at the first floor level. The analysis assumed a metabolic rate of 1.1 met and a clothing level of 0.5 clo. From both tables, we can see that none of the configurations results in thermal comfort conditions that would satisfy the ASHRAE standard. However, the best results are achieved in configuration 7, where the skylight, entrance, side entrance, and first floor window are open. Also, a comparison between configuration 2, in which only the skylight is open, and configuration 7 shows the positive impact that having multiple inlets at different levels can have to improve the impact of the vertical shaft on thermal comfort. Table 4 shows a comparison between the average summer outdoor dry bulb temperature and relative humidity compared with those achieved indoor using configuration 7. With regard to the impact of the chimney, the results showed no noticeable impact for opening the chimney on internal comfort conditions.

Table 2: Average June, July, and August results of CFD simulation for all configurations and zone

	First Floor Zone			Third Floor Zone			Attic Zone		
	T_{db}*	T_{op}*	RH***	T_{db}*	T_{op}*	RH***	T_{db}*	T_{op}*	RH***
Configuration 1	83.2	83.6	58.3	83.2	83.6	58.3	80.3	83.2	62.4
Configuration 2	85.7	86.0	57.5	85.7	86.0	57.5	85.7	86.2	57.5
Configuration 3	84.9	84.9	64.4	86.6	87.7	59.4	88.7	91.5	55.8
Configuration 4	84.3	84.8	64.5	86.7	87.8	59.3	88.8	91.6	55.7
Configuration 5	84.3	85.1	64.5	86.7	87.8	59.2	88.9	91.6	55.6
Configuration 6	84.3	85.1	64.9	86.8	87.7	59.0	89.0	91.7	55.4
Configuration 7	83.9	84.5	65.5	86.1	87.2	60.4	88.3	91.1	56.6

* Tdb = Average summer dry bulb temperature. (°F).
*** RH = Average summer relative humidity (%).
** Tdb = Average summer operative temperature (°F).

Table 3: Resulting thermal comfort parameters for all simulated configurations

	PMV*	PPD**	Thermal Sensation
Configuration 1	1.25	38%	Slightly warm
Configuration 2	1.55	53%	Warm
Configuration 3	1.45	48%	Slightly warm
Configuration 4	1.38	45%	Slightly warm
Configuration 5	1.43	47%	Slightly warm
Configuration 6	1.43	47%	Slightly warm
Configuration 7	1.12	32%	Slightly warm

* PMV = Predicted Mean Vote.
** PPD = Percentage of people dissatisfied.

Table 4: Average summer outdoor conditions compared with average results of configuration 7

	T_{db} outdoor*	RH outdoor**	T_{db}	T_{op}	RH
First Floor Zone	90.9	67%	83.9	84.5	65.5
Third Floor Zone	90.9	67%	86.1	87.2	60.4
Attic Zone	90.9	67%	88.3	91.1	56.6

* Tdb outdoor = Average summer outdoor dry bulb temperature. (°F).
** RH outdoor = Average summer outdoor relative humidity (%)

These results show a clear positive impact from the use of natural ventilation in the Kalteyer House. While it may be difficult for contemporary houses to completely rely on natural ventilation for cooling throughout the overheated season in a climate such as San Antonio, these results demonstrate the potential for passive cooling through natural ventilation to be used for at least part of the time, which could result in significant reductions in energy use, emissions, and utility costs.

CONCLUSION

This study shows that much can be learned from the study of historical buildings, where sensitive architect-designed environmental strategies were implemented with respect to ventilation devices in order to mitigate the problem of summer heat in hot climates. Environmental and climate-adaptive strategies have been used since antiquity, including in Eastern building tradition as well as in some ancient hypogeum or earth sheltered constructions. Analogous approaches have been also historically used in vernacular buildings in the hot and humid climate of the southern United States, with the adoption of architectural elements such as cupolas, wide central halls, dog-trot plans, etc., to enhance ventilation for cooling and, in some cases, de-humidifying the air. The archival and bibliographical research showed that passive cooling ventilation strategies were also adopted in 19th century architectural design, mostly considered by scholars only for its stylistic peculiarity. The architect James Riely Gordon specifically acknowledged in his projects and writings the issues related with the extreme summer heat characterizing Texas's weather, which resulted in the development of specific buildings typologies of courthouses. These typologies included 'signature plans' integrating ventilating shafts and combined towers to create stack ventilation effect, as well as solid masonry buildings to ensure high thermal mass.

Literature review also shows that the whole-building ventilation strategies in nineteenth century context were not only aimed at cooling. In addition to that, great emphasis was in fact given to providing healthy 'sanitary conditions', since the pivotal 1842 Edward Chadwick's report on health sanitary condition of working class (Frederick- Rothwell, 2015). This debate became international and involved not only architects but also experts in the newly created 'sanitary science' and can be well grasped reading professional discourses published in late 19th century American architectural journals (Frederick- Rothwell, 2015).

Further, the results of the CFD computer simulation reveals that the entrance hall of the Kalteyer house, which is characterized by a ventilating shaft, most effectively works when an air flow is generated through the opening of a door or window at the building lower level as well as windows at upper levels. Achieving the best results required keeping the skylight open. The simulation results also clearly show that in the case in which only the skylight is opened, no effective naturally occurring convection flows are created; therefore, no impact is achieved in terms of improving occupant thermal comfort.

The simulation results however show that only one of the created configurations, configuration seven, achieves notable improvements of environmental conditions, as defined in ASHRAE Standard 55, and that Gordon's passive cooling system is not able to reach contemporary comfort conditions during the hottest months of the year without the aid of mechanical systems both with regard to temperature and humidity. However, the improvement shown in configuration 7 still indicated a potential for passive cooling through natural ventilation to contribute to the cooling of the house and potentially reduce the need for mechanical cooling in some parts of the year. Given that cooling represents the largest residential energy end use in this climate, such a mixed mode system could lead to notable reductions in energy use, emissions, and utility costs. Such a system could also be very useful in low income situations in which utility costs represent a significant portion of the family's disposable income where even small reductions in utility costs can have a considerable positive impact.

This paper represents part of a larger investigation aiming to analyze the potential of passive cooling strategies used in the Kalteyer House. Other ongoing phases of the project include the following:

1. Empirically testing the effectiveness of the passive cooling strategies in the home through monitoring the internal environmental conditions that exist through a network of sensors and conducting experiments in which the existing mechanical system is turned off and different configurations of opening and closing doors, windows, and skylights are investigated. The conditions in the house will be monitored during the hottest period of the year, which will allow the research team to compare the simulation results and the monitoring data. In addition to validating the results, this will also allow for evaluating the effectiveness of the CFD simulation, which relied on average climatic data.
2. While the ventilation rates associated with strategic passive designs such as utilized at the Kalteyer House may effectively address issues of occupant comfort, there is a directly related secondary issue that will be addressed in another future study phase, which is: Indoor air quality (IAQ). In the era in which this house was designed and built, there were different concerns about the quality of air with respect to actual occupant health, which concerned 'hygiene' and 'healthy air' to fight infectious diseases considered as a real threat. Current norms accept the association between air exchange rates and IAQ. That being the case, investigators will include monitoring of common poor IAQ markers such as carbon dioxide, VOCs, gas and bioaerosols.
3. Additional simulations will be conducted to investigate how to jointly use passive cooling ventilating shaft and mechanical air conditioning system to reduce the HVAC energy consumption, both achieving comfort conditions and minimum energy use in the hottest periods, responding more favorably to the requirements of energy-saving policies.

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