12th International Conference on Structural Analysis of Historical Constructions
SAHC 2020
P. Roca, L. Pelà and C. Molins (Eds.)

RECONSTRUCTING THE INDOOR CLIMATE OF HISTORIC BUILDINGS

WOLFGANG STUMPF[1*]

[1]Department for Building and Environment
Donau-Universität Krems
Dr.-Karl-Dorrek-Strasse 30, 3500 Krems, Austria
e-mail: wolfgang.stumpf@donau-uni.ac.at, www.donau-uni.ac.at/dbu (*corresponding author)

Keywords: reconstruction, usage, thermal comfort, hygrothermal simulation

Abstract. *In general, a building survey includes geometry, structure, construction, material and history. In historical buildings over the time the building structure and usage can vary greatly. If a room offers good conditions, it will be used accordingly. The usage criteria are not limited to geometric and visual design features but also include thermal comfort. When determining the use of historical rooms and buildings, it makes sense to combine the results of the construction survey and literature research with a reconstruction of the indoor climate. Constructive adjustments, spatial extensions and social developments lead to a deviation from the originally planned and implemented situation over time.*

Which parameters have to be known in order to reconstruct the indoor climate of a historic building? This paper uses three examples to describe the requirements and procedure for determining the use of rooms that are no longer in their original state. The reconstructed spaces are an office in a former tobacco factory in Krems (Austria) [1], an art gallery in Yogyakarta (Indonesia) [2] and a traditional residential building is in Jeddah (Saudi Arabia) [3]. Dynamic thermal and hygrothermal simulations of building elements show the ability of materials to influence the indoor climate and the interaction between construction and indoor climate. By monitoring or defining the user's presence and activities in a room the thermal interaction between construction and indoor climate is calculated. The detection of the airflow around and through the building provides important parameters for the assessment of thermal indoor comfort. The results were compared with the use of space as described in the literature or expected from the building survey.

The method of reconstructing the indoor climate in historical buildings works. The results provide information for evaluating the original situation. With these findings, the potential inherent in a building can be better exploited for the adaptation of historical buildings to changing user requirements or climatic conditions.

1 INTRODUCTION

The thermal conditions of a room have a great influence on its practical use. The choice for material, construction, geometry, orientation and size of the building and its openings is determined in the design process. The quality of construction is limited to the availability of resources and to the state of building techniques. Over the time, parts of the historic construction were adapted to the change of usage or technologies. Such modifications may or may not improve the quality of the building and user comfort. During the life cycle of a building, there are periods, in which the interaction between construction, user comfort and environment are in a good balance. The circumstances in which such precious phases occur are of particular interest for the reconstruction and adaptation of historic buildings. The results provide inspiration or individual solutions for adapting a room or building to another purpose without the need to add new construction technologies or equipment.

This paper describes a method of reconstructing a user's thermal comfort in a room or building, which is no longer available in its original state.

2 MATERIALS AND METHOD

In addition to a conventional building survey specific material characteristic and the air flow around and through the building need to be determined. Temperature, humidity, air velocity in a room, activity and clothing of the user are the main parameters to assess the thermal comfort at a specific usage scenario as it can be expected from the architectural design, the description in literature or explanation from former user. A high thermal comfort confirms the supposed use of space.

Steps to reconstruct the indoor climate to proof a room's usage:

1. use information provided by a regular building survey: plans with detailed measurements of rooms, construction, openings, materials, history, its purpose and way of use, description of the surrounding neighborhood, environment, landscape,
2. find the way of air streaming through the building,
3. determine key values of air velocity in the room or its air change rate,
4. get the outdoor climate data from a database or by monitoring the microclimate on site,
5. determine specific characteristics of construction and surface materials,
6. calculate the indoor temperature and humidity,
7. assess the thermal comfort,
8. discuss and compare the results with its assumed purpose of use.

2.1 Three buildings

The method to reconstruct the indoor climate of a historic building was developed and proved on three buildings. They differ in shape, size, usage, materials, location, respectively climate zone and the data available. All testimonials use natural ventilation for the reduction of overheating. In the current situation, only Gallery 1 in Yogyakarta operates a chiller, but only during the museum's opening hours.

2.1.1. Meeting room at Danube University Krems, Austria

Krems is located in the Austrian province Lower Austria, north of the Eastern Alps at the River Danube. Hot summer and cold winter are significant for the prevailing continental climate. The former tobacco factory in Krems was designed by architect Paul Hoppe (1869-1933) and built in 1918-1922. Since 1994, it has become the main building of Danube University Krems Campus, housing office rooms and lecture halls. The building with its typical facades is a listed monument (figure 1, left).

Between June and September, indoor temperature in the examined meeting room rise up to 32 degrees Celsius. Due to the development of cooling strategies, a system of numerous sensors has been monitoring the thermal behavior of one exemplary room without inner heat gains and its adjacent spaces since May 2018. The dataset includes the outdoor air temperature, indoor air temperatures and surface temperatures of the meeting room and all adjacent rooms, the use of the room, door, window wings and shading system (figure 1, right).

The façade construction consists of a reinforced concrete skeleton with massive brick in between, covered with whitewashed cement plaster with structural façade elements and whitewashed lime cement plaster on the inner wall side. Two layers of eight slim wooden wing frames with single glass form one big box window. A textile roller blind between the two window layers protects the room from solar radiation. A metal stud wall planked with gypsum boards detaches the room from the northern office, other walls are made of massive brick, covered with whitewashed lime cement plaster. The reinforced concrete ceiling construction is based on the Hennebique System. Mineral wool, screed and a wooden floor form the floor construction. The bottom view of the ceiling shows suspended gypsum boards. The originally dedicated use of this room was an office using night ventilation. Due to fire restrictions and for the protection from wind, rain and uninvited guests it is not possible respectively not allowed to keep windows open at night.

Figure 1: Danube University Krems, former tobacco factory (2019, [4]). The examined meeting room in the second floor, left of the risalit (2019, [4]).

2.1.2. Gallery 1 in Museum Affandi, Yogyakarta, Indonesia

The city of Yogyakarta is located on the Indonesian island Java. The climate is hot and humid with a permanent smooth wind breeze.

The Gallery building was designed by the painter and sculptor Affandi (1907-1990, figure 2, left), built in 1962 and officially opened in the year 1974. The lenticular gallery is defined by two curved massive brick walls covered with cement plaster. In the west wall, a bend of slide windows provides fresh air for the gallery. Air enters the building through large doors at the ends of the east wall. Ceramic tiles cover the floor slab made of reinforced concrete. Banana leaves gave inspiration for the shape and construction of the roof. Teak shingles on wooden roof battens are the original roof materials. Due to leakages, the roof was insulated with an additional layer of bituminous shingles. Natural light enters the building through a small glass slit among the longitudinal axes in the middle of the ceiling. A canvas underneath the transparent roof area protects the paintings from direct light (figure 2, right).

After an earthquake in 2010 and due to significant changes in the surrounding area (more traffic, noise, dust, insects, neighboring buildings, reduced airflow, change of microclimate) ventilation openings in the upper area of the east facade were closed [2]. This measure led to uncomfortable room climate for art and visitors. Therefore, two chillers were installed in 2016 to support ventilative cooling. Every morning wardens open doors and windows to exchange the humid, warm air with fresh air from outside. Chillers operate during opening hours only. During night, doors and windows are closed, cooler, but more humid outdoor air enters the gallery through gaps between windows and roof and through gaps in the door fillings.

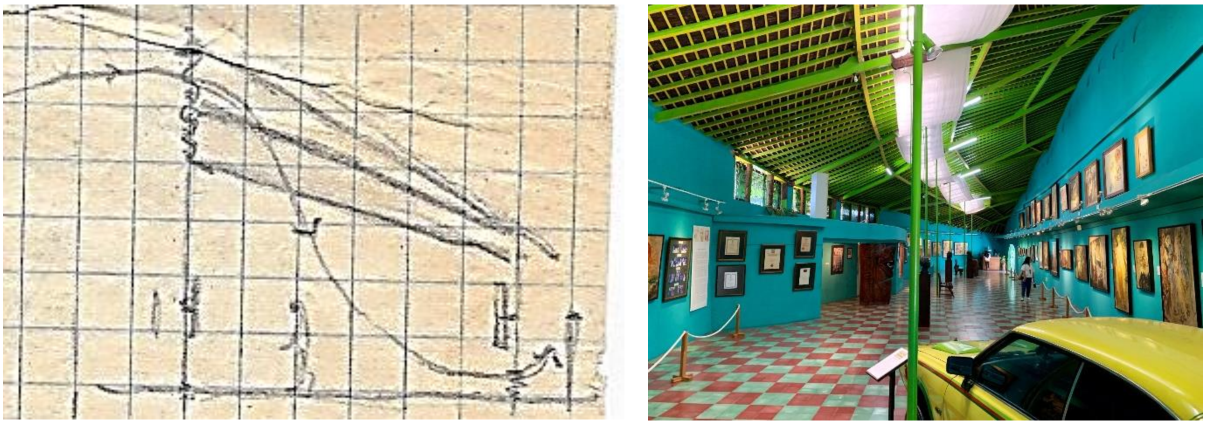


Figure 2: The design sketch for Gallery 1 with an implied ventilation concept (right, sketch 65 in Sketchbook of Affandi, 1950). Gallery 1 in Yogyakarta (W. Stumpf, 2019).

2.1.3. Al Nawar House in Jeddah, Saudi Arabia

Al Nawar House is a traditional residential building in Al Ballad, the old town of Jeddah, Saudi Arabia. The climate in the port city on the Red Sea is very hot and humid all year round. A smooth breeze permanently blows alternately from the Red Sea or from the desert of Arabian Peninsula. Outdoor temperatures are between 32 and 49 degrees Celsius, at night about 15 degrees lower. Coral stone was the only construction material for historic buildings in this area. Wooden window boxes, so called roshan or rawasheen, are the typical elements on these lime-plastered, mostly whitewashed façades. They protect the rooms from direct sunlight and unwanted glances. Their main function is the control of airflow in the building.

In 2012, a team of scientists from University of Technology Vienna and King Abdulaziz University Jeddah performed a comprehensive building survey of the about 350-year old Al Nawar House in Al Ballad [3]. As a result, there are detailed plans, a description of building, construction, material and its history (figure 3).

The people in such buildings knew how to create a tolerable indoor climate by opening and closing the shutters at certain times. The room function could change over a day. Depending on the air temperature, humidity and air velocity the indoor climate was suitable for sleeping, sitting down for a chat or doing manual work. There was no support from mechanical air conditioning systems.

Nowadays, most of such historic buildings are abandoned, or only the ground floor is used as a department store or as storage space. Since 2014 the old town of Jeddah has been listed as UNESCO World Heritage. The municipality plans to revitalize this historic urban area.

2.2 Building survey

The three chosen examples differ in the data availability of its initial situation and in the access to the building.

Which information was available, what was needed?

The meeting room at Danube University Krems, Austria, provides all necessary information. Geometry of the actual situation, construction and material characteristics are given. The author has personal access to the room at all times. Microclimate (outdoor air temperature, wind, precipitation), air and surface temperature in the examined and adjacent rooms have been monitored under several usage scenarios since 2018 [4].

The author visited Gallery 1 in Yogyakarta, Indonesia, in August 2018 and August 2019. Documents and plans about the current state of the building, geometry of the actual and historic situation, construction and material characteristics are given [2]. The original state of the building has changed in some parts, but the usage is still as it has been from the beginning. Microclimate (outdoor air temperature, humidity, wind and precipitation), indoor air temperature, humidity and even CO_2-concentration have been monitored since January 2019. Data are permanently accessible via WLAN connected sensors and internet cloud. Surface temperatures, operation hours of chillers, air velocity at different areas in and around the building, thermal comfort were measured and experienced personally on site over two periods of two weeks. Air velocity in the initial situation with numerous small openings in the façade and no buildings around Gallery 1 have to be determined.

Information about Al Nawar House in Jeddah obtain from several sources like construction plans, literature and interviews. The author had no direct contact to this building nor to the region. The state of geometry and construction in the year 2012 when the building already was abandoned, construction and the material characteristics are given [3] (figure 3). A meteonorm climate data set [5] describes the outdoor climate in the area of Jeddah. The microclimate around the building site has to be derived from meteonorm data. The building owner and scientists performing the building survey described the indoor climate and the former use of the building. Literature and material database MASEA [6] provided further information.

Figure 3: Floor plan of Al Nawar House in Jeddah, second floor (left), north direction points to the right. The examined room 101 (right) is situated on the top right of the floor plan (building survey in 2012, TU Wien [7]).

2.3 Airflow around and in the building

The determination of air velocity is based on calculations with characteristic values and the consideration of influencing factors. In addition to classic results of a building survey, this step provides further information.

The interaction between indoor and outdoor climate is influenced by heat transmission through the building envelope, by solar radiation entering a room through openings or transparent areas and by convection from air streaming into or out of a building. This paper focuses on buildings with small or well-shaded openings, so that the indoor climate is only slightly affected by sunlight. The described method of reconstructing the indoor climate is aimed at buildings such as Affandi Gallery 1 and Al Nawar House, where convection has the greatest influence on the heat and moisture transport. For the reconstruction of indoor climate, it is necessary to determine the hourly air change rate (ACH) of a room. In a qualitative building and site analysis the way of airflow around, into and through a building can be identified with curved lines and arrows on the plans. Alternatively, a CFD simulation (Computational Fluid Dynamics) based on Navier-Stokes equations offers more specific information [3].

Air movement is stimulated by wind (air flows from areas with high pressure to areas with low pressure) and buoyancy (vertical differences in air temperature respectively density). Numerous circumstances reduce the flow of ambient air into a building. Main parameters are vegetation and constructions in the surrounding, building shape, position of the building to the wind direction, size of an opening and the resistance of fillings like lattice are. The airstream in a room depends on the number, size and position of openings, size and proportion of the room, surface finish and temperatures, objects and heat sources in the room, and especially on the spatial distribution of temperature and pressure differences. Flow reduction also can be calculated by an exact analysis of each influence parameter according the established laws of aerodynamics in a quite complex way. If the examined space is still in its original structure and surrounding a tracer gas measurement delivers realistic numbers for ACH. For an early stage analysis as described in this paper, the reduction factor is estimated from the effects of the parameters written above.

The number of air changes per hour (ACH) is calculated using equation 1 and 2. Direction-dependent values for the wind velocity come from a climate database or a microclimate monitoring system on site.

$$v = S \cdot s \cdot R \tag{1}$$

$$ACH = v / V \tag{2}$$

v [m3/h] stands for air volume per hour, S [m2] is the value for open cross-sectional area of a room or an opening, s [m/h] stands for the average wind or air velocity over an investigated period, R [-] is an estimated reduction factor in the range from 1 to 0, V [m3] describes the room volume, ACH [1/h] is the air change rate per hour.

Realistic key values for air velocity in a room range from 0.05 to 2.0 m/s. The air change rate per hour during operation (person in the room) ranges from 0.1 (windows or shutters closed, but just for a few hours) to 3.0 and is usually controlled by the user. ACH values between 1.5 and 10 per hour can be assumed during night ventilation (no person in the room, all windows opened).

The envelope of the three examined buildings is not particularly airtight or even fully closed.

The box windows in Krems comply with the current technical standard for existing buildings. In Gallery 1 the air gap between the wall and roof above the windows in the eastern façade is eight centimeter wide. The windows in Al Nawar House have no glass panes, but wooden shutters and wooden lattice, so called Mashrabiya. Leakages in the building envelope are taken in account in ACH with 0.1 to 0.3 per hour.

2.4 Calculation of indoor climate

Why calculating the indoor climate? A building survey gives us the opportunity to reconstruct the geometry, construction, material, use and history of buildings in their previous and original state. Similar, still existing constructions or material samples offer a comparison option for creating virtual models. We can agree that no thermometer or hygrometer was normally installed in historic buildings and that no profiles from measured indoor temperature and humidity were documented. Historical scenes on paintings, traditional clothing, typical widespread diseases etc. indirectly provide hints about temperatures, humidity, air drafts in buildings.

The indoor climate is mainly perceived by temperature, humidity and movement of air. Chapter 2.3 describes the determination of airflow and ACH. Equation (3) and (4) give indoor air temperature and humidity [7].

$$\begin{aligned}(c_{wall} \cdot A_{wall} + c_{ceiling} \cdot A_{ceiling} + c_{floor} \cdot A_{floor} + c_{air} \cdot V \cdot \rho) \cdot \Delta T_i / \delta t \\ = (c_{air} \cdot ACH \cdot V \cdot \rho + U_{wall} \cdot A_{wall} + U_{win} \cdot A_{win}) \cdot (T_e(t) - T_i(t))\end{aligned} \tag{3}$$

$$C_{hyg} \cdot \Delta u_i / \delta t = ACH \cdot V \cdot (u_e(t) - u_i(t)) \tag{4}$$

c is the effective specific heat capacity of a building component reacting with the room air, ISO DIN 13786 [8] describes the calculation method using thickness, bulk density, specific heat capacity and thermal conductivity of a material layer. A denotes the room-side surface of a component. V is the volume of ventilated space, ρ the air density. T_i and T_e are indoor and outdoor air temperature over time step t. T_e comes from a climate database or a microclimate monitoring on site. The examples described in chapter 3 did not consider any differences in the climate data between the current time and the time before climate change. ACH describes the air change per hour, see equation (2). The U-value or heat transfer coefficient of a building component depends on the thickness and thermal conductivity of material layers. u is the absolute air humidity, converted from the relative humidity, air pressure, saturation pressure and the gas constant. The calculations of U and u follow common building physical procedures. Values for equation (3) and (4) come from building survey, material databases or equation (1) and (2).

The results show temperature and humidity profiles over time (figures 4 to 7). For the validation of the indoor climate model, compare the calculations with the monitoring data (chapter 3.1, figures 4 and 5). Mean values over a time period in which the room is occupied are input data for the assessment of thermal comfort.

2.5 Assessment of thermal comfort

Usage criteria of a room are not limited to constructive, geometric and visual design features but also include thermal comfort. A room is used according its purpose, if comfortable climate conditions correspond to the activities and requirements of the user. If this premise is not met, the assumptions from building survey cannot be confirmed or the user satisfaction was quite low.

The thermal comfort was assessed with the “CBE Thermal Comfort Tool” [9], an online tool, in which one of the standardized assessment methods as described in EN ISO 7730 [10], EN 16798-1 [11] and ASHRAE 55 [12] can be chosen. Building history, calculations or assumptions provide the input data for this tool. Air temperature and relative humidity result from equation (3) and (4). Operative temperature is the average of air and surface temperature. To do this, the area-weighted value of all surface temperatures must be defined, which were calculated using dynamic simulation software like WUFI pro [13]. In climate zones where outdoor air temperature lies in the range of indoor air temperature you may specify the surface temperature plus/minus three degree Celsius of the indoor air temperature. Classify a person’s activities and clothing as described in the building’s history. For the evaluation of air velocity follow the procedure in chapter 2.3.

The adaptive method is based on an approach in which the acceptance of higher indoor temperatures increases with higher outdoor temperatures.

The result of thermal assessment is indicated by the position of a point in a diagram and the values for PMV and PPD (Predicted Mean Vote and Percentage of Person Dissatisfied [10], figure 8). If results do not meet the standardized requirements, it should be taken into account that the assessment methods were developed in accordance to the lifestyle of the so-called western world in the second half of the 20th century. In this case, individual results are evaluated based on their relative relationship to comparable situations.

3 RESULTS

One room of each described building was examined under different usage scenarios and different climate conditions. The results show the quality of the thermal comfort and the congruence of reconstructed and described or expected situations.

3.1 Meeting room in Krems, Austria

This building was used to test and calibrate the method. In 2019, several scenarios using different control strategies for window and shading positions, could be investigated in real-time and under personal appearance. These experiments were the base for checking the congruence between monitored and calculated indoor climate.

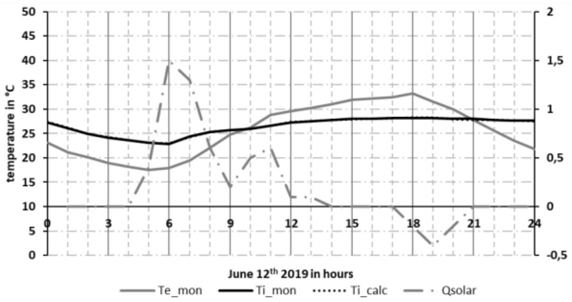


Figure 4: Monitored (Ti_mon) and calculated (Ti_calc) indoor temperature profiles over one day in the meeting room in Krems, Austria. The calculated temperature profile overlaps the measured values.

The calculations proof that the indoor air temperature can be predicted if specific data about the outdoor air temperature and the room usage profile (window, shading and door position, occupancy) are known.

Textile roller blinds and windows are always drawn. The curve indicating the calculated indoor temperature overlaps the monitored temperature profile. The air change rate and heat flow from solar radiation (Qsolar) through the shaded window had to be adjusted in the hourly calculations according the usage and time profile (figure 4).

3.2 Gallery 1 of Museum Affandi in Yogyakarta, Indonesia

Museum Affandi gives an example for how to reconstruct the initial design concept's indoor climate.

In a first step, the calculated temperature and humidity profiles were adjusted to the monitored data in an iterative way. The air change rates were determined taking into account the reduction parameters described in chapter 2.3. The load profile "Qsolar - Qchiller" (solar radiation through the roof glass minus cooling capacity of the chiller) results from the remaining difference between monitored and calculated temperature profile (figure 5, left diagram). The dehumidification performance of the chiller also results from the difference between monitored and calculated humidity profiles (figure 5, right diagram).

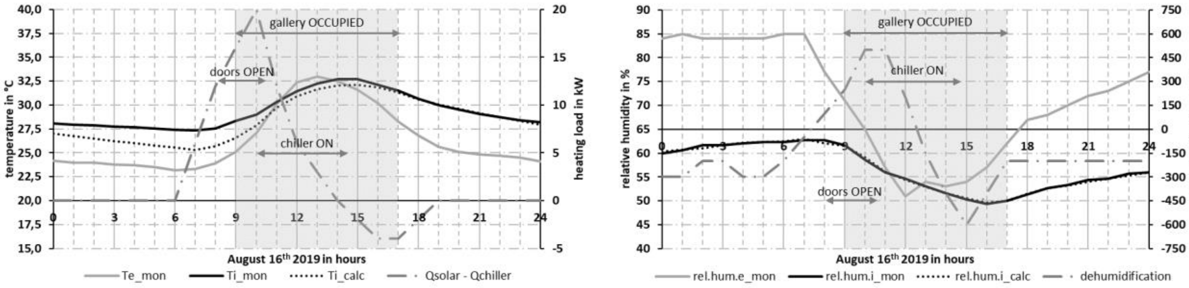


Figure 5: Indoor climate in Gallery 1 on August 16, 2019. The diagram on the left shows the approximation of the calculated (Ti_calc) to the monitored (Ti_mon) indoor temperature, taking into account the influence of solar radiation through the glass opening in the roof and the cooling capacity of the chiller. The right diagram shows the humidity profiles under the influence of the chiller's dehumidification capacity.

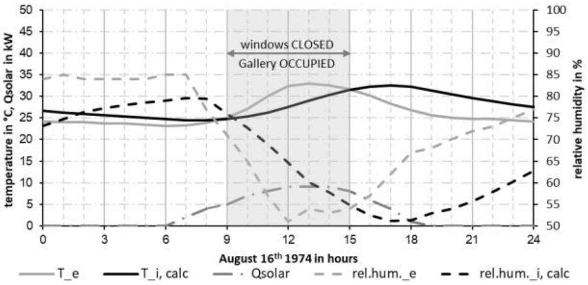


Figure 6: Reconstructed indoor climate of Gallery 1 in its original state in 1974, when there were numerous small ventilation openings in the east façade and no chillers were in operation.

In a second step, the indoor climate of Gallery 1 was reconstructed in its initial state in 1974 (figure 6). The main differences to the current state are additional small ventilation openings in the east wall construction, door wings with a wide-meshed, open metal grille, no neighboring buildings around the museum site and therefore stronger wind, no chillers in the gallery. These features are reflected in higher air change rates. The windows in the west façade were kept closed during the day when outdoor temperature was higher than the temperature in the gallery. Due to open windows and wind pressure, a slightly higher air exchange rate was assumed at night. The same microclimate data as in 2019 was used for the calculations.

During opening hours in 2019 temperature is higher than in 1974, relative humidity is quite the same. The chiller offers the advantage of its ability to dehumidify the air, increase the air velocity in its streaming area and lower the airflow temperature well below the temperature of surrounding areas. This provides cool areas for the visitors, but is not a healthy environment for the art on display.

3.3 Al Nawar House in Jeddah, Saudi Arabia

The third example only usess information from a building survey in the year 2012, when it already has been abandoned for many years. Literature and an interview with the owner and former inhabitant of Al Nawar House were the sources to reconstruct the way of living under extreme climatic circumstances. The author never had the opportunity to see the building in reality. By organizing a climate data set and additional information about the construction, the indoor climate was calculated according chapter 2.

The result shows that the thermal comfort in room 101 on a hot and humid day in October the 8th between 9 and 14 hours is in an acceptable range (figures 7 and 8). The construction in its original state fits to its use.

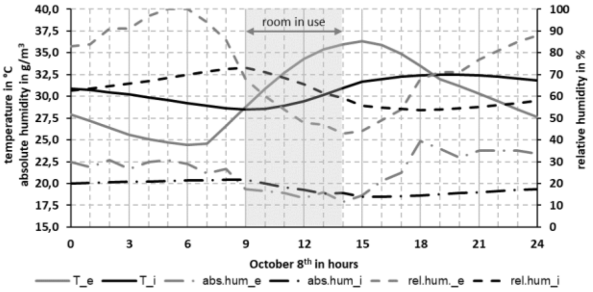
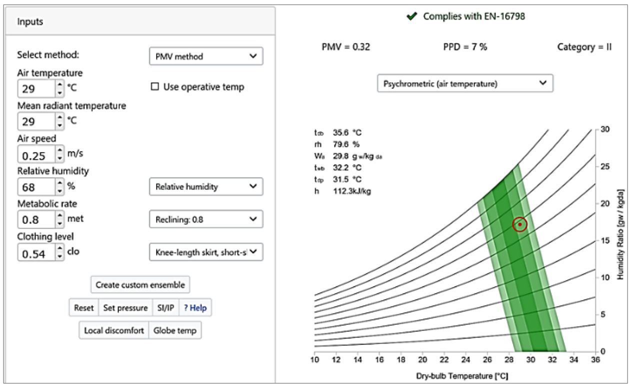


Figure 7: Reconstructed indoor climate of room 101 in the originally inhabited Al Nawar House on a hot and humid day.

During these hours the air temperature in the room is lower than the outdoor temperature, outdoor absolute and relative humidity are lower than in the room. A smooth breeze streams around and above the building. When the user enters the room, he opens the shutters of the roshan, warm air enters the room from outside and flows through the building. Smooth wind over the rooftop tries to suck air out of the building. The breeze in the lanes pushes warm air through the opened roshan into the cooler room. Due to an open connection from room 101 to the rooftop through adjacent rooms and the staircase warm air is driven by buoyancy and wind pressure. For the calculation an air change rate ACH of 5 times per hour was determined. Considering the rotating movement of air in the room the air velocity next to the floor of 0.25 meters per second was calculated by equation (2). Under the circumstances of 29 °C, 68% relative humidity, air velocity of 0.25 m/s, seated activity, summer clothes the Berkeley Thermal Comfort Tool assesses the situation as a second-class comfort (figure 8). This means, that this room in its construction, materials, shape, position of openings provides quite good conditions for the users even on a very warm and humid day.



Inputs

Select method: PMV method

Air temperature 29 °C

☐ Use operative temp

Mean radiant temperature 29 °C

Air speed 0.25 m/s

Relative humidity 68 % (Relative humidity)

Metabolic rate 0.8 met (Reclining: 0.8)

Clothing level 0.54 clo (Knee-length skirt, short-s)

✓ Complies with EN-16798

PMV = 0.32 PPD = 7 % Category = II

Psychrometric (air temperature)

t_{db} 35.6 °C
rh 79.6 %
W_a 29.8 g_w/kg_{da}
t_{wb} 32.2 °C
t_{dp} 31.5 °C
h 112.3kJ/kg

Figure 8: The Berkeley Thermal Comfort Tool [9] confirms a proper indoor climate in room 101 between 9 and 14 hours on a very hot and humid day in October.

4 CONCLUSIONS

The described method of reconstructing the indoor climate in historical buildings works. The application of this method requires a little extra effort to collect and document additional data for dynamic thermal simulations of construction components and buildings.

A closer cooperation between archaeologists, architects, historians and building physicists provides new perspectives on the results of a conventional building survey and supports the proof of concepts based on the investigations of individual groups. With these findings, the potential inherent in a building can be better exploited for the adaptation of historical buildings to changing user requirements or climatic conditions.

The results of this paper describe a first step in the holistic reconstruction of the thermal behavior of buildings that are no longer in their original state. Additional parameters for the determination of airflow around, into, in and through building, parameters for the reconstruction of solar impact through building envelope’s transparent openings shall be the motive for further research.

New technologies enable a more in depth building analysis but such approaches require interdisciplinary collaboration between different branches of science.

Acknowledgements. Research reported in this publication about Gallery 1 in Yogyakarta, Indonesia, was jointly supported by the ASEAN-European Academic University Network (ASEA-UNINET), the Austrian Federal Ministry of Education, Science and Research and the Austrian Agency for International Cooperation in Education and Research (OeAD-GmbH). Research reported in this publication about meeting room in Krems, Austria, was part of the research project CoolAIR [4], which was supported by the Austrian Research Promotion Agency FFG, Austria.

REFERENCES

[1] Stumpf, W.; Winkler, M.; Trauninger, D.; Treytl, A.; Bratukhin, A.: CoolAIR – Automatisierung von Kastenfenstern zur Raumkühlung. Fachhochschule Burgenland, Tagungsband e-nova "Gebäude der Zukunft?", Band 22: p. 59-66, Leykam Buchverlagsgesellschaft, Graz, Austria 2018.

[2] Herbig, U.; Styhler-Aydın, G.; Grandits, D.; Stampfer, L.; Pont, U.: The Architecture of the Affandi Museum – Approaches to a Piece of Art. 3rd Biennale ICIAP - International Conference on Indonesian Architecture and Planning, Yogyakarta, Indonesia 2016.

[3] Jaeger-Klein, C.; Stumpf, W.; Styhler-Aydin, G.; Radinger, G.: Analysis of Building Structures and Valorization of Cultural Heritage in Jeddah (KSA). In: Proceedings of the 10th International Conference on Structural Analysis on Historical Constructions, SAHC 2016, Leuven, Belgium: p. 77, Taylor and Francis Group, London 2016.

[4] CoolAIR – Prädiktiv geregelte passive Gebäudekühlung mittels natürlicher Nachtlüftung und tageslichtoptimierter Verschattung, research project at Danube University Krems, www.donau-uni.ac.at/de/universitaet/fakultaeten/bildung-kunst-architektur/departments/bauen-umwelt/forschung/projekte/coolair.html, accessed January 15, 2020.

[5] meteonorm – Irradiation data for every place on Earth. Meteotest, Bern, Switzerland, www.meteonorm.com, accessed January 15, 2020.

[6] MASEA – Materialdatensammlung für die energetische Altbausanierung. Fraunhofer-Institut für Bauphysik, Valley, Germany, www.masea-ensan.de. Accessed January 15, 2020.

[7] Stumpf, W.; Bednar, T.: Hygrothermal Behaviour of Building Components in Context with the Room Usage of a Historic Residential Building in Jeddah, KSA. TU Delft, WTA 4th International PhD Symposium, Proceedings, Delft, Netherlands 2017.

[8] ISO DIN 13786 Wärmetechnisches Verhalten von Bauteilen – Dynamisch-thermische Kenngrößen – Berechnungsverfahren (ISO 13786:2017), Beuth Verlag GmbH, Berlin, Germany, 2018.

[9] CBE Thermal Comfort Tool, Center for the Built Environment, University of California Berkeley, https://comfort.cbe.berkeley.edu, accessed January 15, 2020.

[10] ÖNORM EN ISO 7730:2006 Ergonomie der thermischen Umgebung – Analytische Bestimmung und Interpretation der thermischen Behaglichkeit durch Berechnung des PMV- und des PPD-Indexes und Kriterien der lokalen thermischen Behaglichkeit (ISO 7730:2005). Austrian Standards, Vienna Austria, 2006.

[11] ÖNORM EN 16798:2019 Energetische Bewertung von Gebäuden – Teil 1: Eingangsparameter für das Innenraumklima zur Auslegung und Bewertung der Energieeffizienz von Gebäuden bezüglich Raumluftqualität, Temperatur, Licht und Akustik – Module M1-6, Austrian Standards, Vienna, Austria, 2019.

[12] ASHRAE 55-2017 Thermal Environmental Conditions for Human Occupancy. American Standard by ASHRAE, 2017.

[13] WUFI pro – Wärme und Feuchte instationär. Standard program for evaluating moisture conditions in building envelopes, Fraunhofer Institute for Building Physics, Stuttgart, Germany, www.wufi.de, accessed January 15, 2020