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The Rietveld Schröder House is not only an icon of Dutch architecture, but also a museum welcoming about 18,000 visitors each year. The unusual experimental character of the construction and the fact that the house is open to the public can be expected to affect the indoor climate and to pose some risks for the conservation of the building and the furniture. In order to assess possible risks related to the indoor climate and, if necessary, take measures, a monitoring of the indoor climate was carried out in 2017.

The monitoring was aimed at answering the following questions:

- What is the indoor climate and its response to the outdoor climate?
- What is the effect of visitors on the indoor climate?
- What are the risks posed by the indoor climate to the conservation of the objects and the building, and what measures can be taken to minimize those risks?

The research included a survey of the state of conservation of the building and furniture and monitoring of the indoor and outdoor climate; data were elaborated in order to answer the research questions listed above.

SURVEY

Prior to the monitoring, a visual survey of the state of conservation of the building and the furniture was carried out; this was repeated at the end of the monitoring programme. Thermographic images were collected as well. The moisture content of the wooden window frames was indicatively evaluated by means of a moisture meter (based on electrical resistance). Information on the type of heating system, number of visitors, opening times and other possibly relevant facts were collected.

MONITORING OF THE CLIMATE

The temperature and relative humidity (RH) of the air on the ground and first floors of the building [FIG. 5.1], were measured at 15-minute intervals for more than a year; additionally, the climates in the skylight and in the basement were recorded for a period of several months. The temperature at the construction surface was monitored for different materials (wood, masonry, steel frame), to assess the risk of surface condensation. The outdoor climate (temperature and RH) was monitored as well.

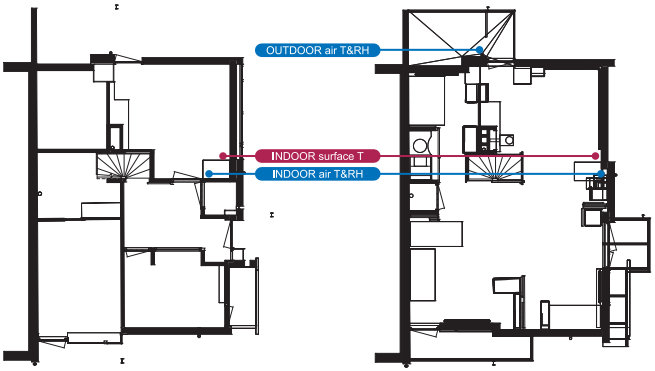

FIG. 5.1 Location of the sensors on the ground (left) and 1st (right) floor.

As well as calculating several statistical parameters, including averages and fluctuations, data were elaborated using the Climate Evaluation Chart (CEC), generated by the web tool available at http://www.monumenten.bwk.tue.nl/. This chart provides a clear overview of all data in a single graph.

The effect of visitors on the indoor climate was assessed by comparing periods in which the building was open to the public (Tuesday to Sunday, from 11:00 to 17:00) with those in which the building was closed.

The indoor climate was analysed with special attention to the air humidity. Based on the difference between the water vapour pressure inside and outside the building during the winter months, the indoor climate class of the building, defined according to R. van Hees[1], was assessed.

Moreover, the correspondence of the indoor climate to the specifications defined for indoor climates in museums in the ASHRAE handbook was checked.[2] Depending on the building class (based on the type of construction, use, and climate control system) and the outdoor climate, the ASHRAE handbook defines several 'classes of control' options, ranging from D (only prevent dampness) to AA (precision control) [TABLE 5.1]. These classes indicate what can feasibly be achieved in terms of indoor climate, depending on the type of building (e.g. presence of insulation, single- or double-glazed windows, type of construction materials, etc.) and existing system of climate control (e.g. heating, ventilation, air conditioning, etc.). For each of the ASHRAE classes, different risks for the conservation of the objects can be expected. Considering the type of construction of the Rietveld Schröder House (uninsulated, single-glazed windows, heating with no control for air humidity), it seems reasonable to expect that the building may well fulfil the specifications for control class C. Therefore, the correspondence of the indoor climate to the specifications for class C (RH within 25 to 75% RH year-round) was checked.

In order to evaluate the risks for the conservation of the furniture, we first referred to the ASHRAE specifications [TABLE 5.2].[3] However, ASHRAE guidelines do not mention the risks when the climate only fits the control class for part of the time. Moreover, the listed risks cannot be easily linked to a specific type of objects (wooden furniture, in this case). To overcome these limitations, the evaluation of the possible risks posed by the indoor climate to the object concerned was carried out following the approach proposed by M. Martens[4] and the web tool at http://www.monumenten.bwk.tue.nl/. The main purpose of this approach is to consider the response time of the object (i.e. the time the object takes to respond to changes in temperature and RH) and its mechanical behaviour. Two main degradation mechanisms are considered: biological (moulds) and mechanical (plastic deformation). Among the classes of objects available, the class 'furniture' was selected for the evaluation of the risks. The calculations for this class of objects was originally developed by Martens based on the case of a a lacquered wooden object;[5] this object class was considered most similar to the furniture present in the Rietveld Schröder House out of the four classes of objects available.

CATEGORY OF CONTROL	BUILDING CLASS	TYPICAL BUILDING CONSTRUCTION	TYPICAL TYPE OF BUILDING	TYPICAL BUILDING USE	SYSTEM USED	PRACTICAL LIMIT OF CLIMATE CONTROL	CONTROL CLASS OPTION
Uncontrolled	I	Open structure	Privy, stocks, bridge, sawmill, well	No occupancy, open to all viewers all year.	No system	None	D (if benign climate)
	II	Sheathed post and beam	Cabin, barn, shed, silo, icehouse	No occupancy. Special event access	Exhaust fans, open windows, supply fans, attic venting. No heat.	Ventilation	C (if benign climate) D (unless damp climate)
Partial control	III	Uninsulated masonry, framed and sided walls, single-glazed windows	Boat, train, lighthouse, rough frame house, forge	No occupancy. Summer tour use. Closed to public in winter.	Low-level heat, summer exhaust ventilation, humidistat heating for winter control.	Heating, ventilation	C (if benign climate) D (unless damp climate)
	IV	Heavy masonry or composite walls with plaster. Tight construction; storm windows	Finished house, church, meeting house, store, inn, some office buildings	Limited occupancy. Staff in insulated rooms, gift shop. Walk-through visitors only. No winter use.	Ducted low-level heat. Summer cooling, on/off control, DX cooling, some humidification. Reheat capability.	Basic HVAC	B (if benign climate) C (if mild winter) D
Climate controlled	V	Insulated structures, double glazing, vapour retardant, double doors	Purpose-built museum, research library, gallery, exhibit, storage room	Unlimited occupancy. Education groups. Good open public facility.	Ducted heat, cooling, reheating, and humidification with control dead band	Climate control, often with seasonal drift	AA (if mild winters) A B
	VI	Metal wall construction, interior rooms with sealed walls and controlled occupancy	Vault, storage room, display case	No occupancy. Access by appointment.	Special heating, cooling and humidity control with precision constant stability control.	Special constant environments	AA A Cool Cold Dry

TABLE 5.1 Classification of climate control potential in buildings (ASHRAE 2007)

TYPE	SET POINT OR ANNUAL AVERAGE	MAXIMUM FLUCTUATION AND GRADIENTS IN CONTROLLED SPACES			COLLECTION RISKS AND BENEFITS
		CLASS OF CONTROL	SHORT FLUCTUATIONS PLUS SPACE GRADIENTS	SEASONAL ADJUSTMENTS IN SYSTEM SET POINT	
General Museums, Art Galleries, Libraries, and Archives	50% RH (or historical annual average for permanent collections) Temperature set between 15 °C and 25°C	C Prevent all high-risk extremes	Within 25 to 75% RH year-round. Temperature rarely over 86°F, usually below 77°F.		High risk of mechanical damage to high-vulnerability artefacts; moderate risk to most paintings, most photographs, some artefacts, some books; tiny risk to many artefacts and most books. Chemically unstable objects unusable within decades, routinely less at 86°F, but cold winter periods double life.

TABLE 5.2 Temperature and RH specifications, and risks and benefits for collection for control class C (ASHRAE 2007)

FIG. 5.2 Deformation of thin timber elements of furniture

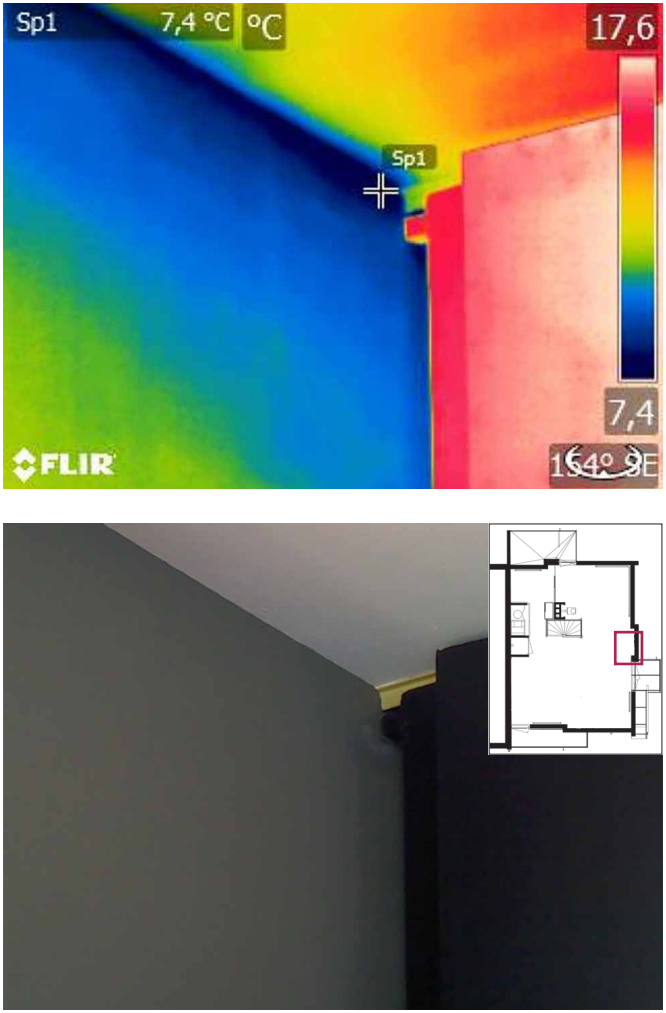

FIG. 5.3 Surface temperature in a corner of the construction, top: IR image, bottom: normal image; the insert shows the plan of the 1st floor with the location (in red) of the inspected area

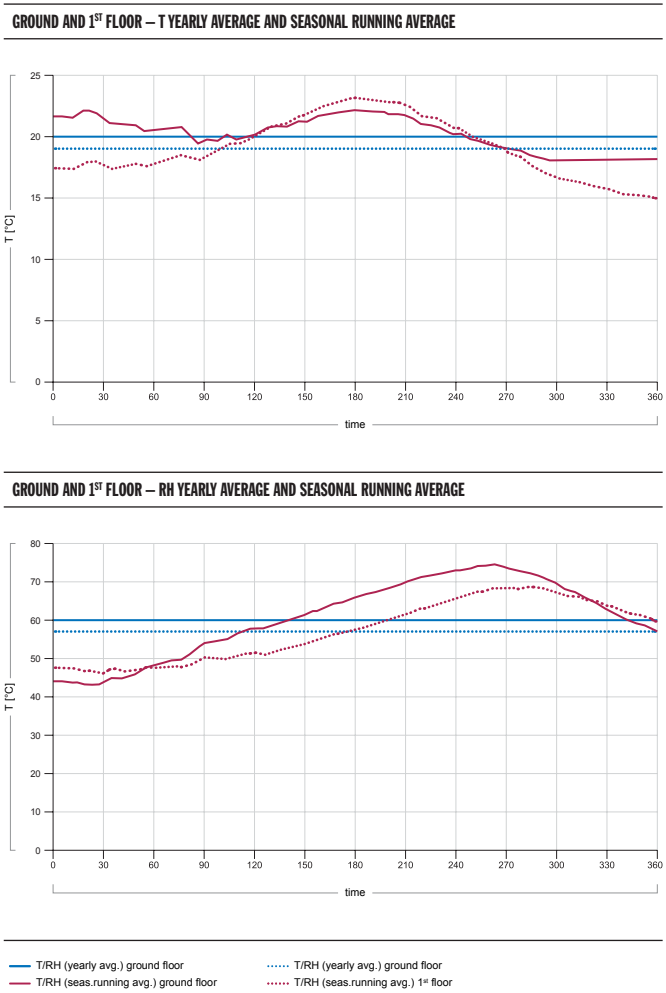

FIG. 5.4 Temperature and RH yearly and seasonal average on the ground and 1st floor.

RESULTS

The state of conservation of the building, as assessed visually, is good. The moisture content measured in the timber window frames is low and no moisture spots, indicating the presence of moisture due to e.g. leakages or surface condensation, were observed on the walls of the building. The only exception was the study on the ground floor where parts of the plaster layer detached in 2016. Possible cause was moisture infiltration and measures were taken; later measurements of the moisture content showed that the masonry was dry.[6]

The state of conservation of the furniture is generally good. However, some pieces of furniture, mainly the thinner parts, are visibly deformed [FIG. 5.2].Floor finishes (carpet and linoleum) become worn due to use and are regularly replaced.

INDOOR CLIMATE: EFFECT OF OUTDOOR CLIMATE AND VISITORS

Thermographic images made it possible to identify thermal bridges in corners and at connections between walls and ceiling in the external envelope of the building [FIG. 5.3].

When analysing the indoor climate data, periods with high temperature values (and corresponding low RH values) in the months January-March 2017, are immediately evident: these are due to malfunctioning of the heating system; this problem was solved in April 2017.

The yearly and seasonal temperatures and RH averages on the ground and first floors are reported in figure 5.4. Based on these values it can be concluded that the average temperature and RH are higher on the ground floor than on the first floor. When daily T and RH variations are considered, larger variations are recorded for the first floor than for the ground floor. This suggests that the climate on the first floor is more affected by variations in the outdoor climate.

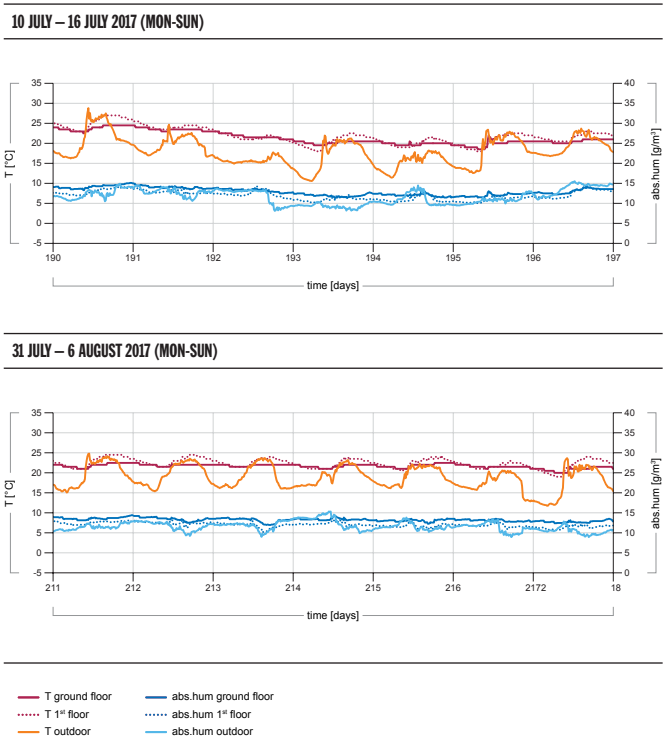

FIG. 5.5 Indoor and outdoor temperature and absolute humidity on the ground and 1st floor during two weeks in the summer period

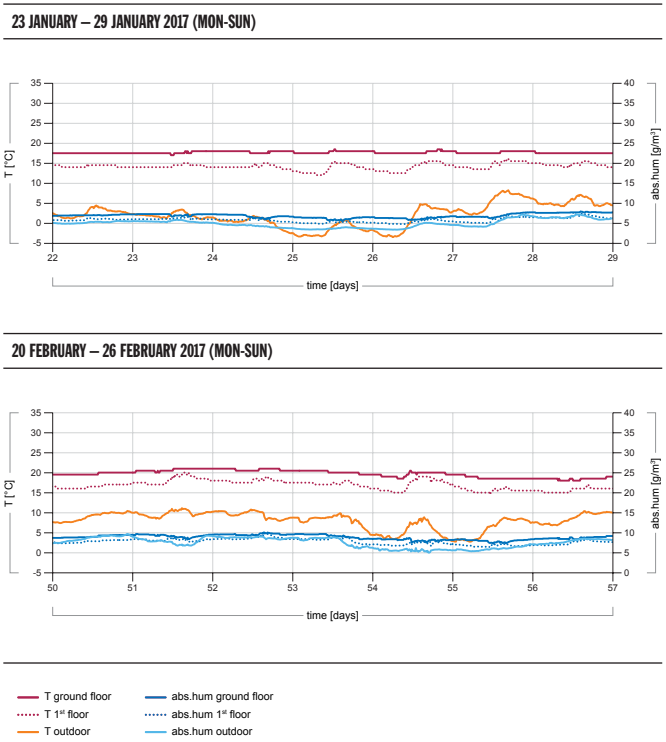

FIG. 5.6 Indoor and outdoor T and absolute humidity on ground and 1st floor during two weeks in the winter period

This conclusion is confirmed when the indoor climate is correlated with the outdoor climate: the strong influence of the outdoor climate on the indoor climate is evident in the summer months, when the heating system is not in use; this is clearer on the first floor [FIG. 5.5], mainly due to the presence of large window surfaces and stronger (natural) ventilation.

The highest RH values are registered at the end of the summer period and in autumn, when the outdoor air is most humid; the lowest values are recorded during winter, when the heating system is active.

The presence of visitors has no evident effect on temperature and absolute humidity in the building: it is not possible to distinguish any peak in temperature and/or indoor absolute humidity during the visiting hours; not even during winter [FIG. 5.6], which might have indicated the production of heat or moisture by people. This means that ventilation nullifies any effect produced by visitors and confirms that the building is open to the outdoor climate.

In the skylight, large variations in temperature due to sun radiation were recorded. The temperature in the basement is very stable throughout the year, whereas the RH varies considerably, with the highest values recorded in the summer period.

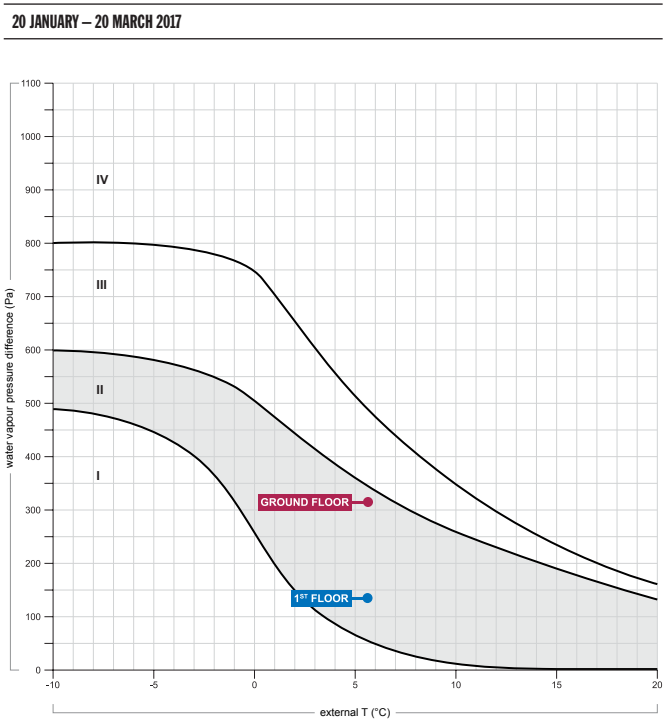

FIG. 5.7 The indoor climate class on the ground and first floors of the building (the period between 20/01/17 and 20/03/2017 was considered)

RISKS FOR THE CONSERVATION OF BUILDING AND FURNITURE RELATED TO THE INDOOR CLIMATE

First of all, in order to assess the risk of surface condensation and/or mould growth, the indoor climate is compared to the classes of indoor climate as defined in Van Hees (1986);[7] the ground floor is more humid than the first floor, but both fall within climate class II, which means that the indoor climate is sufficiently dry [FIG. 5.7]. Therefore, in principle (under the current regime) no moisture problems in the sense of surface condensation or mould growth on the building construction are to be expected.

FURNITURE	RISK OF MOULD	LIFETIME MULTIPLIER	RISK FOR BASE MATERIAL
Ground floor	safe	0.745	safe
First floor		0.877	safe

TABLE 5.3 Result of the elaboration performed using the web tool available at http://www.monumenten.bwk.tue.nl/ for the evaluation of risks posed by the indoor climate to the conservation of different types of objects; in this case the results for the object category 'furniture' were considered.

The absence of surface condensation is confirmed by the measurements of the surface temperature and the calculation of the resulting RH at the surface. Despite no surface condensation being detected, high values of air RH (> 80-85% RH) might still lead to biological growth on plaster and wooden surfaces in the event of extended periods of high RH; in addition, variations in RH and temperature might lead to risks for the conservation of the building materials and furniture. These risks are further examined. First the correspondence of the indoor climate to the specifications for ASHRAE climate control class C, which is the expected class, was assessed. Figures 5.8 and 5.9 show that, when considering RH specifications, 88% and 98% (for the ground floor and first floor respectively) of RH values are within the given criteria for class C. In summer and autumn, there is still a significant percentage of values which exceed the RH requirements; this percentage is higher for the ground floor than for the first floor. No risk of fungal growth was detected. A few temperature values exceeded 30 °C (due to malfunctioning of the heating system), while a significant number of values exceeded 25°C in the spring and summer period (mostly on the first floor). For climate control class C, according to the ASRHAE guidelines,[8] risks of mechanical damage are mainly present for highly vulnerable objects and for paintings, some books and some artefacts [TABLE 5.2]. However, as the ASRHAE does not further specify which type of artefacts, and the indoor climate does not fully meet the specifications for class C, it is difficult to draw conclusions as to the risks for the conservation. Another approach, which considers the response of the material to the indoor climate,[9] was therefore adopted (see above). Table 5.3 reports the outcome of this elaboration, performed using the web tool at http://www.monumenten.bwk.tue.nl/.

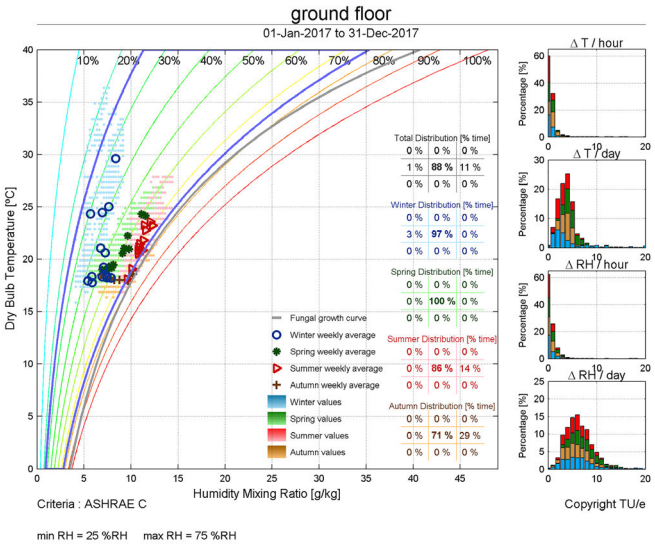

FIG. 5.8 Temperature and RH data recorded on the ground floor of the building in 2017 compared to the specifications for class C; graphical elaboration performed using the web tool available at http://www.monumenten.bwk.tue.nl/

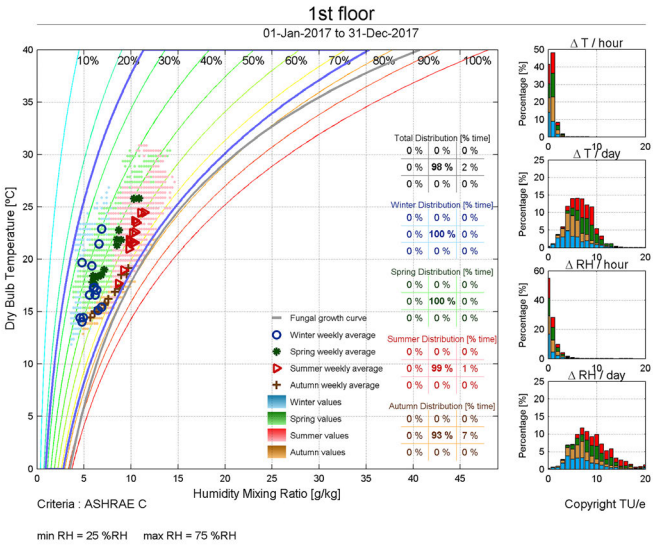

FIG. 5.9 Temperature and RH data recorded on the first floor of the building in 2017 compared to the specifications for class C; graphical elaboration performed using the web tool available at http://www.monumenten.bwk.tue.nl/

Based on these results it is possible to conclude that the indoor climate is safe as far as the wooden furniture is concerned; neither biological growth (germination and growth of spores) nor mechanical damage are to be expected. However, the lifetime multiplier (LM), is relatively low, especially for the ground floor, which means that the service life is lower than it would be in ideal conditions (stable 20 °C and 50% RH).

CONCLUSIONS AND RECOMMENDATIONS

Based on results of the climate monitoring, it can be concluded that the current indoor climate is mainly governed by the variations in the outdoor climate; this is most evident on the first floor. The effect of the visitors on the indoor climate is negligible. This is most probably due to the small number of visitors (10-12 persons for each guided tour) and to the high ventilation due to the quite open building structure.

During the heating season, periods with higher than desirable temperatures and lower than desirable RH values were recorded, mainly due to a malfunction of the heating system. During the summer season, very high RH values were recorded.

The indoor climate of the building falls largely within the ASHRAE class of control C, which can be considered the class of control possible for this building (uninsulated masonry, single-glazed windows, heating without RH control). The risk to the furniture of mechanical damage and biological growth is low.

Based on the results of the monitoring, it is suggested that the indoor temperature and RH level be monitored, and an alarm system used so as to be able to intervene promptly in case of malfunctioning of the heating system.

In order to reduce RH in the summer, air dehumidification should be considered. Ventilation will not be sufficient, as the absolute outdoor humidity during summer is high.

When considering the indoor climate under the current heating and ventilation regime, there is no reason to reduce the number of visitors.

No immediate risks of biological growth or mechanical damage have been detected. The option of replacing the original pieces of furniture with copies, might still be considered if the lifetime needs to be optimized or when other risks (e.g. mechanical damage caused by visitors) need to be avoided.

No immediate risk of biological growth or surface condensation was detected in the present situation. However, as several severe thermal bridges are present in the construction, the risk of mould growth on the construction might arise should interventions like sealing of windows be undertaken without simultaneously introducing RH control.