

Gelati Monastery Complex

Environmental Monitoring Programme



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Context

Gelati Monastery Complex, in particular, the Church of the Virgin Mary and St. George, is characterized by complex technology as well as the condition of wall painting and architecture. Severe damages/deterioration are caused by multiple and intertwined factors. There were many damaging factors on the monument throughout the history of the churches. In order to eliminate them, the process of full-scale rehabilitation of the Gelati monastery complex began in 2010. Unfortunately, the interventions carried out in 2015-20, especially the roofing, turned out to be a significant damaging factor for the Gelati complex. During the rehabilitation process the water was infiltrated through the roof of the Church of the Virgin Mary, in the interior. Furthermore, on the west arm, infiltration process was ongoing until August 2020. From 2020-21 temporary roof was installed on both, St. George's and Vigin Mary's churches, which prevented further water infiltration through the roofs. In 2022 August-September, the under the temporary covering roof of the west arm of the Church of the Virgin, was removed to let moisture evaporate (the roof under the temporary cover is still open).

Moisture content in the structure and unstable environmental conditions can still be considered as main provocative factors for the wall painting deterioration (particularly salt activity) at the Gelati monastery complex.

Unstable environmental condition is an activation mechanism for wall painting deterioration. It is a factor that indirectly affects the monument, however over time it accelerates the process of deterioration of the condition of its building and painting materials. Environmental monitoring along with liquid moisture survey and salt investigation plays an important role in scientific conservation research of the paintings. Apart from studying macro and microclimate, moisture content in structure and salt investigation it is necessary to know the physical history, condition of the wall painting, original and added material and based on this knowledge determine and implement appropriate conservation needs especially environment related mitigation measures.

Methodology

The following issues were addressed in order to determine the impact of macroclimate on the microclimate and other sources acting on the microclimate, in addition to the objectives of the long-term environmental monitoring program of Gelati Monastery Complex:

1. Characterization of the macro climate of the village Gelati

- Determination of climatic zone according to geographical location
- Processing of the climatic conditions (temperature, relative humidity, amount of atmospheric Precipitation (rain), wind speed, direction).
- Processing of air temperature and relative humidity data collected by a sensor installed in the yard of Gelati Monastery Complex (determination of the impact of atmospheric precipitation on humidity and temperature taken from the simulation archive)

2. Determining the factors affecting the microclimate of the Church of the Nativity of the Virgin and St. George

In general, the microclimate is determined by 2 main factors: 1. Macroclimate: Temperature and humidity access into the building from the outside (macroclimate)/ the thermal conductivity of the building and the vapor permeability of water. (Note air exchange) 2. Except for macroclimates, humidity and / or other additional sources of temperature. (Eg in the case of moisture with water infiltration and capillary rise; e.g. in the case of temperature with the activity of people in the church).

The permeability of the building and the availability of other additional sources

of moisture / temperature depend on:

- Building type (distribution of spaces, openings) - sources of air exchange
- On the technology of the original and added material - hygroscopicity of the material characteristic of moisture absorption and subsequent release of moisture; On the thermal behaviour of the material (ability to receive heat and cool). The material may change its physical and / or chemical properties under the action of moisture and temperature. For example: increase or decrease the volume, change the color, etc. An important factor is the surface temperature of the building material, which depends on the condensation event (transition of water vapor into a liquid form), which damages the original technology / material surface.
- On church Usage / Function - Possible Sources of Air Circulation, Humidity, and Temperature: Monastery service and visitor influence, frequency of openings, cleaning methods that may change humidity and temperature.
- On the current condition / architectural condition of the church - (eg roof condition, temporary roofing, water supply systems, groundwater impact) Failure to do so may result in increased humidity in the interior (ie infiltration and capillary movement of water into the structure).
- And conservation / restoration and monitoring works (eg works may disrupt the normal cycle of air circulation, cause temperature and humidity changes while being on the scaffolding ...

Macroclimate monitoring includes following parameters: Ambient Temperature, Relative Humidity, Absolute Humidity (cal), Dew point temperature (cal), Atmospheric precipitation (rain), Wind (speed, direction).

3.1 Characterization of the microclimate of the Church of the Nativity of the Virgin and determination of the influence of the macroclimate

- Analysis of relative humidity, absolute humidity and air temperature data (with minimum and maximum values) on a monthly and seasonal basis.

➤ Determining the condensation event at the Church of the Nativity of the Virgin

- Analysis of temperature and dew point data in seasonal and monthly sections. (From March 2024 it is planned to install surface temperature sensors)

Characterization principle / categorization

- Comparison of horizontal section and exterior data of the main space of the church

- Comparison of vertical section and exterior data of the eastern arm of the main space of the church

- Comparison of vertical and horizontal section and exterior data of the western arm of the main space of the church

- Comparison of the northern equestrian and gate gates of the temple with exterior data

- Comparison of the south chapels and entrances of the church with the exterior data (annexes were described separately)

- Comparison of church's narthex and exterior data

Principle of characterization / categorization

To determine the influence of microclimate on the main space of the church from the main space of the (narthex and entrances) were compared separately:

- Details of the south arm, south entrance and exterior of the church
- Details of the north arm, north entrance and exterior of the church
- Narthex and exterior data of the western arm of the church

3.2 Characterization of the microclimate of the Church of the St George and determination of the influence of the macroclimate

- Analysis of relative humidity, absolute humidity and air temperature data (with minimum and maximum values) on a monthly and seasonal basis.

➤ Determining the condensation event at the St. George

- Analysis of temperature and dew point data in seasonal and monthly sections. (From March 2024 it is planned to install surface temperature sensors)

4 Components of the baseline data of the environmental monitoring strategy

- Duration of monitoring: 1 year (minimum)
- Data recording interval: every 1 hour
- Recorded data settings: Relative humidity (int, ext) and temperature (int, ext), atmospheric precipitation (ext), wind speed and direction (ext)
- Calculated parameters: Absolute humidity (int, ext) and dew point (int, ext)
- Start date of monitoring: 2-3 December 2020 (for more please see Chronology of environmental monitoring activities in Gelati Monastery complex since December 2020)

Data collection: The equipment donated in Gelati Churches stores relative humidity and temperature data on a memory card built into the device.

Due to the fact that access to certain locations in Gelati Monastery is limited, two models were purchased when choosing the monitoring equipment: 1) Hobo Datalogger MX1101, which downloads data via Bluetooth, using the appropriate application Smartphones. MX1101 allows the sensor to be installed in a location with limited access 2) Hobo Datalogger UX100-011A, whose data is downloaded via USB cable, using the appropriate software. The UX100-011A has been installed in accessible locations (UX100-011A, were fully replaced with MX1101 models in 2022).

The equipment installed in Gelati monastery works on elements whose lifespan depends on the frequency of data collection, the frequency / amplitude of the change of environment, the activity of the screen and the frequency of data write-off. Note that the sensors must be re-loaded programmatically when replacing the batteries. Therefore, in order to maximize data protection and extend the life of batteries, it is recommended that the frequency of data unloading be kept to a minimum;

Chronology of environmental monitoring activities in Gelati Monastery complex since December 2020:

Date	Monitoring programme	Executor	Report
December 2020 – December 2021	Parameters: RH, AT, AH (cal), DPT (cal); Interval: 1 hour Sensor in the Church of Virgin: Interior: Hobo UX100-011 (12 items); Hobo MX1101 (only in apse – 2 items); Sensor in the Church of St. George: Hobo MX1101 (3 items); Exterior: Hobo MX2301A (Please find an attached folder 00 Sagaradze 2021)	National Agency for Cultural Heritage Preservation of Georgia (NACPG) Mariam Sagaradze (2020 – September 2021)	M. Sagaradze, 'Environmental monitoring: winter, spring and summer seasons (5-12-2020–18-09-2021), Church of the Nativity of the Virgin Mary, Gelati Monastery Complex', unpublished report, 2021.
December 2021 – April 2022	Parameters: RH, AT Interval: 1 hour Sensor in the Church of Virgin: Sensor: Interior: Hobo MX1101 (only in apse – 2 items); Exterior: Lost (Please find an attached folder 02 National Environmental Agency 2021_2022)	The National Environment Agency ordered by Cultural Heritage Agency (NACPG)	No report. Excel or/and Csv raw data
December 2021 – June 2022	Parameters: RH, AT Interval: 1 hour Sensor in the Church of Virgin: Sensor: Interior: Hobo UX100-011 (12 items); Exterior: Lost	The National Environment Agency ordered by Cultural Heritage Agency (NACPG)	No report. Excel or/and Csv raw data

	(Please find an attached folder 02 National Environmental Agency 2021_2022)		
July 2022 July 2023	<p>New programme: Parameters: RH, AT Interval: 10 minutes (logging started on different time) Sensor in the Church of Virgin: Interior: Hobo MX1101 (13 items) Under west arms roof Hobo MX1101 (1 item)</p> <p>Sensor in the Church of St. George: Hobo MX1101 (1 item);</p> <p>Exterior: Weather Station from The National Environment Agency (min, max and average AT, RH in every 10 minutes) other parameters: wind, atmospheric precipitation)</p> <p>(Please find an attached folder 02 National Environmental Agency 2021_2022; 04 Gelati_Committe_2022_2023)</p>	The National Environment Agency ordered by Cultural Heritage Agency (NACPG)	No report. Raw (hobo, Csv and excel) data, Excel spread sheet with average calculations from December 2020 – December 2022
July 2023 on-going October 2023	<p>New programme: Parameters: RH, AT Interval: 30 minutes (logging started at the same time) Sensor: Interior: Hobo MX1101 (13 items)</p> <p>Exterior: Weather Station from</p>	<p>Gelati Rehabilitation Committee</p> <p>Wall painting conservation team – Mariam Sagaradze</p>	

	<p>The National Environment Agency (min, max and average AT, RH in every 10 minutes) other parameters: wind, atmospheric precipitation)</p> <p>In addition, from October 2023 - Exterior: Hobo MX2301A was installed and programmed as interior sensors</p>		
December 2023 – ongoing	<p>New programme: Parameters: RH, AT Interval: 1 hour (logging started at the same time) Sensor: Interior: Hobo MX1101 (16 items) (in south, north and east arms upper level sensors has been added) Exterior: Weather Station from The National Environment Agency (min, max and average AT, RH in every 10 minutes) other parameters: wind, atmospheric precipitation) In addition, from October 2023 - Exterior: Hobo MX2301A was installed and programmed as interior sensors</p>	<p>Gelati Rehabilitation Committee Wall painting conservation team – Mariam Sagaradze</p>	

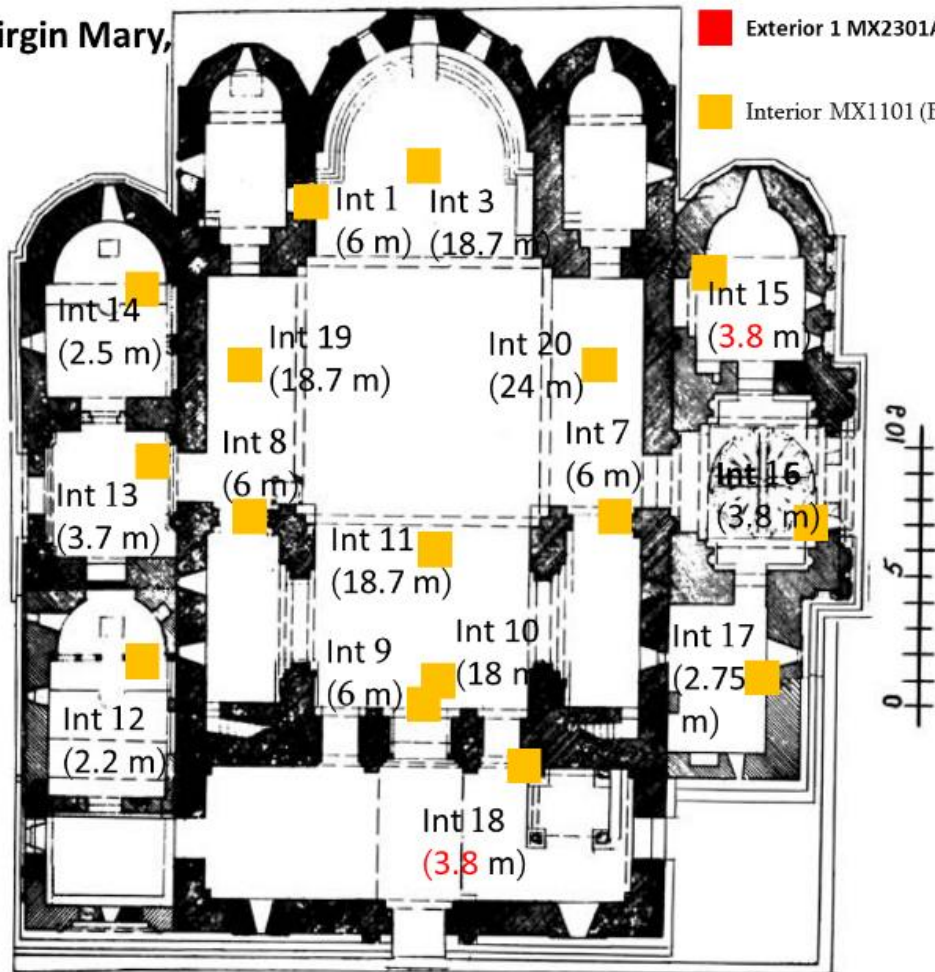
Sensor locations

Church of The Virgin Mary,

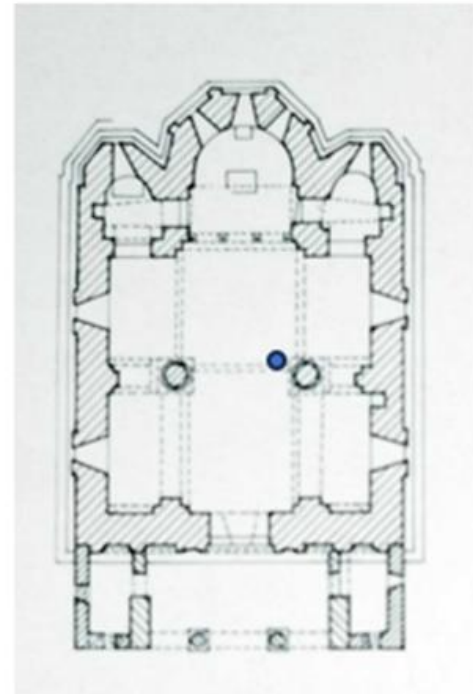
■ Exterior 1 MX2301A (Bluetooth) 2023

■ Interior MX1101 (Bluetooth)

■ Exterior 1



Church of St. George



ბ. ბელაიტი, გეგმა.

სენსორის/ მოწყობილობის ლოკაცია Sensor/device locations	ლოკაციის აღწერა/ Description of the locations	სენსორის/ მოწყობილობის მოდელი და სერიული ნომერი/ sensor/device model and derail number	სენსორის/ მოწყობილობის სახელი Sensor/device file name	სენსორის/ მოწყობილობის ფაილის სახელი Sensor names for plan	საზომი ფარამეტრები Measuring parameter	ჩამოტვირთვის ინსტრუქცია Instructions for downloading	სიზუსტე (ინფორმაცია მოცემულია მოწყობილობების ინსტრუქციიდან) Accuracy for data sheet	ფოტო Photo
Exterior	The yard of Monastery Complex near North gate.	MX2301A 21742999	Gelati_Ext_21742999	Ext	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Vardzia_Agency_Ext , press readout, save as .csv file and copy it on a computer. For further information consult MX2301A manual.	±0.25 °C from -40° to 0°C ±0.2 °C from 0° to 70°C ±2.5% from 10% to 90% typical to a maximum of ±3.5% including hysteresis at 25°C; below 10% RH and above 90% RH ±5% typical.	Yes
Weather Station National Environmental Agency), Exterior	The yard of Monastery Complex near North gate.	N/A			RH (%), AT (°C), Atmospheric precipitation, wind (speed, direction)	Through National Environmental Agency	N/A	Yes
Main Church, Apse (East arm), Lower level. In the opening of Prothesis (Northern upper room)	Height: 6 m	MX1101 21485413	MS_Eastarm_Lower4 13	Int 1	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int1, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±0.21°C from 0° to 50°C ±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	Yes
Main Church, Apse (East arm), upper level on the metal hook	Height: 18.7 m	MX1101	MS_Eastarm_upper_	Int 3	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int2, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±0.21°C from 0° to 50°C	Yes
Main Church, North Arm, upper level on the metal hook	Height: 18.7 m	MX1101	MS_Northarm_upper 395	Int 19	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int3, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	Yes

Main Church, North Arm, lower level (opening from the north-west part of the pastophorium)	Height: 6 m	MX1101 21494870	MS_Northarm_Lower 870	Int 8	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int4, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±0.21°C from 0° to 50°C	Yes
Main Church, South Arm, upper level on the metal hook	Height: 18.7 m	MX1101	MS_Southarm_Upper 388	Int 20	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int5, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	Yes
Main Church, South Arm, lower level (opening from the south-west part of the pastophorium)	Height: 6 m	MX1101	MS_Southarm_Lower 867	Int 7	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int6, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±0.21°C from 0° to 50°C	Yes
Main Church, West Arm, upper level, Eastern part, on the metal hook	Height: 18.7 m	MX1101 U21485405	MS_Westarm_U2148 5405	Int 11	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int5, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	Yes
Main Church, West Arm, upper level, western part on the scaffolding	Height: 18 m	MX1101 U21485408	MS_Westarm_U2148 5408	Int 10	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int6, press readout, save as .csv file and copy it on a computer. For	±0.21°C from 0° to 50°C	Yes

						further information consult MX1101 manual.		
Main Church, West Arm, lower level, on the balcony (central part)	Height: 6 m	MX1101 21485407	MS_westarm_L21485 407	Int 9	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int5, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	Yes
North-west chapel	On the Iconostasis, on the wooden frame of the southern entrance; height: 2.5 m	MX1101 21494869	NWchapel_21494869	Int 12	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int6, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±0.21°C from 0° to 50°C	Yes
North Entrance	South-east pillar capital Height: 3,7 m	MX1101 21494868	North_Entr_2149486 8	Int 13	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int5, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	Yes
North-east chapel	On the Iconostasis, on the wooden frame of the southern entrance; Height: 2.2 m	MX1101 21494871	NEchapel_21494871	Int 14	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int6, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±0.21°C from 0° to 50°C	Yes
South-east chapel	North wall, on the pillar capital; Height: 3.8 m	MX1101 21485410	SEchapel_21485410	Int 15	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int5, press readout, save as .csv file and copy it on a computer. For	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	Yes

						further information consult MX1101 manual.		
South Entrance	South wall, on the western pillar capital; Height: 3.8 m	MX1101 21485412	South_Entr_21485412	Int 16	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int6, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±0.21°C from 0° to 50°C	Yes
South-west chapel	South wall, small niche next to the window. Height: 2.75 m	MX1101 21485411	SW_Chapel_21485411	Int 17	RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int5, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	Yes
Narthex	Near Ciborium, on the capital of the pillar Height 3.8 m	MX1101 21485406	Narthex_21485406		RH (%), AT (°C)	Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int6, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±0.21°C from 0° to 50°C	Yes
Church of St. George	Southern column, on the capital towards the center; Height: 3.4 m	MX1101 21485409	Gel_StG_21485409			Download HOBOMobile app. Connect to the logger via Bluetooth. Select logger: Gelati_Agency_Int5, press readout, save as .csv file and copy it on a computer. For further information consult MX1101 manual.	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C; below 20% RH and above 80% RH ±6% typical.	

Device data sheet

Equipment model	MX1101	MX2301A
Measured parameters	RH/ Temp	outdoor temp/RH
Battery life:	1 year, typical with logging interval of 1 minute. Faster logging and/or statistics sampling intervals, entering burst logging mode, and remaining connected with the app will impact battery life. Excessive readouts, audible alarms, and paging all impact battery life. Visual alarms and other events can have a marginal impact on battery life. <i>(For 30 min logs - 2.2 years)</i>	2 years, typical with logging interval of 1 minute and Bluetooth Always On enabled; 5 years, typical with logging interval of 1 minute and Bluetooth Always On disabled. Faster logging intervals and statistics sampling intervals, burst logging, remaining connected with the app, excessive downloads, and paging may impact battery life.
Battery Type:	Two AAA 1.5 V alkaline batteries, user replaceable	2/3 AA 3.6 Volt lithium, user replaceable
Memory:	128Kb (84,650 measurements, maximum)	128 KB (63,488 measurements, maximum)
Transmission range:	Bluetooth Low Energy (Bluetooth Smart) Approximately 30.5 m line of sight	Bluetooth Low Energy (Bluetooth Smart) Approximately 30.5 m line of sight
Temperature range:	-20° to 70°C	-40 to 70°C
Temperature accuracy:	±0.21°C from 0° to 50°C	±0.25°C from -40 to 0°C ±0.2°C from 0 to 70°C
Temperature resolution:	0.024°C at 25°C	0.01°C
Temperature response time	7:30 minutes in air moving 1 m/s (2.2 mph)	3 minutes, 45 seconds in air moving 1 m/sec
Temperature drift:	<0.1°C (0.18°F) per year	

RH range:	1% to 90%, non-condensing	0 to 100% RH, -40° to 70°C; exposure to conditions below -20°C or above 95% RH may temporarily increase the maximum RH sensor error by an additional 1%
RH accuracy:	±2.0% from 20% RH to 80% RH typical to a maximum of ±4.5% including hysteresis at 25°C (77°F); below 20% RH and above 80% RH ±6% typical	±2.5% from 10% to 90% (typical) to a maximum of ±3.5% including hysteresis at 25°C (77°F); below 10% RH and above 90% RH ±5% typical
RH resolution:	0.01%	0.01%
RH response time	20 seconds to 90% in airflow of 1 m/s (2.2 mph)	15 seconds in air moving 1 m/sec
RH drift:	<1% per year typical	<1% per year typical
Sensor Size:	3.66 X 8.48 X 2.29 cm	10.8 x 5.08 x 2.24 cm
Sensor weight:	56g	75.5g
LCD:	LCD is visible from 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range	No screen
Download:	Bluetooth Smart (Bluetooth Low Energy, Bluetooth 4.0); Download HOBOMobile app. Connect to the logger via Bluetooth. Select the logger: press readout; save as .csv file and copy it on a computer. For further information consult MX1101 manual.	Bluetooth Smart (Bluetooth Low Energy, Bluetooth 4.0); Download HOBOMobile app. Connect to the logger via Bluetooth. Select the logger: press readout; save as .csv file and copy it on a computer. For further information consult MX1101 manual.

Note: Surface temperature sensors need to be purchased. The international council of Gelati Rehabilitation Committee has suggested following:

“Surface Temperature sensors (PT 100) in 2-3 height profiles (on 25 m 4-5 loggers) can help to assess condensation risks, (semi-) quantify water adsorption from the air into the plaster/masonry. Testo provides loggers with 4 sensor slots, there are probably also alternative ones. They should be installed in March, and run through the next year. Fixed within lacunae or on stone”