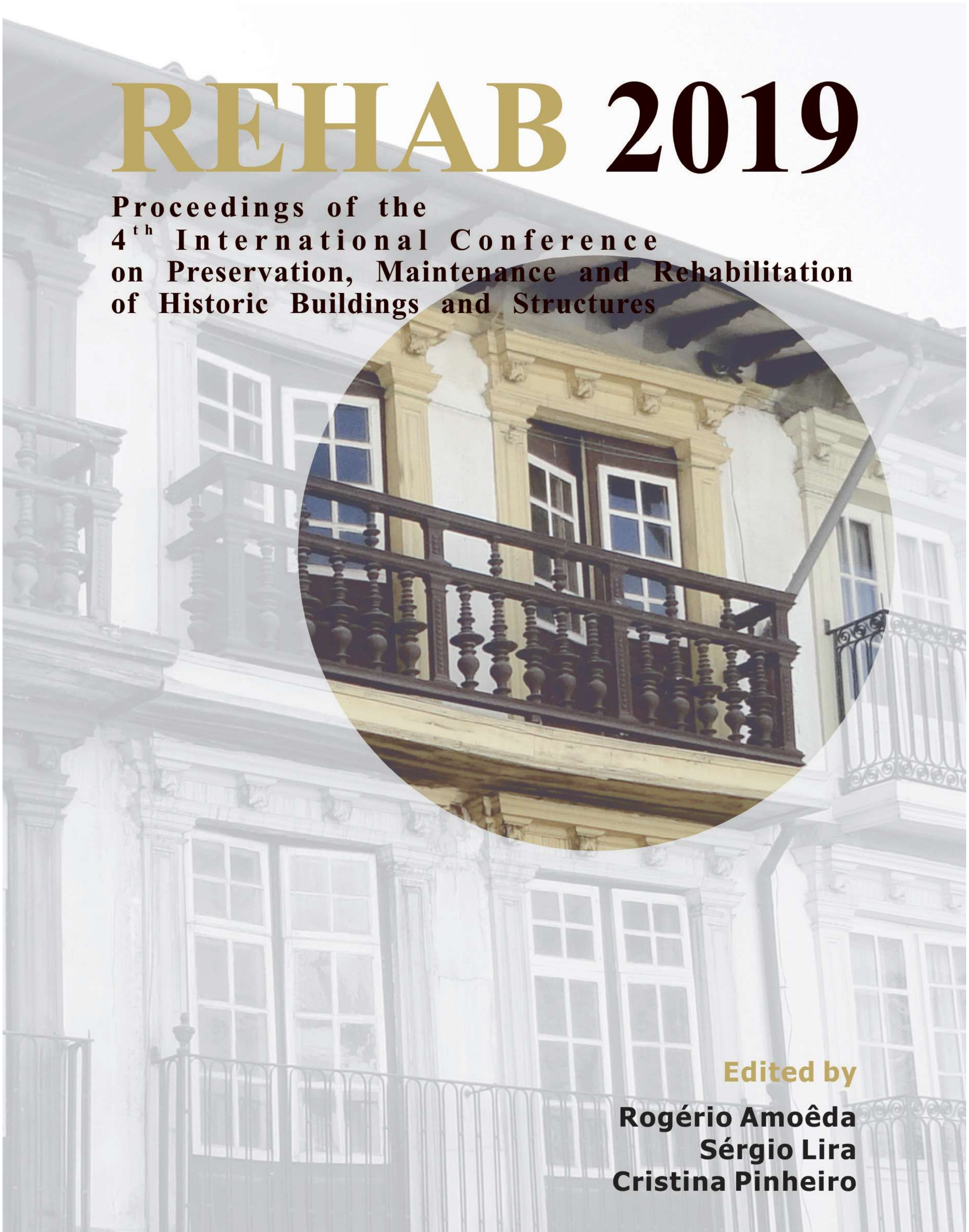

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Sustainable Management of Historical Buildings

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ABSTRACT: The aim of the on-going project „Sustainable Management of Historical Buildings“ is to create administration and management tools for the sustainable development of cultural heritage realty. The project will provide tools for identification and optimization of technical and economic limits of such properties, with an emphasis on the specifics of cultural heritage.

The project itself consists of several successive stages. In the first stage the status of existing structures is evaluated. We focus mainly on non-destructive or semi-destructive methods (monitoring deformations, crack openings, vibration level from outer sources, moisture, temperature etc.) as it is not possible, or only to a limited extent, to use destructive methods of exploration. The aim is to find optimization for complex procedure of diagnosis of historical buildings.

The second stage is to establish optimal maintenance or remediation procedures based on the state of construction, when both common and specialized procedures are considered taking into account the historical character of the building.

The final stage has to determine the cost of maintenance or remediation work. For this purpose a special pricelist is compiled that is based on the evaluation of the already repaired or reconstructed historical buildings.

The results of all stages will then be incorporated into a software tool. After specifying the object type and basic design, this software tool provides an optimal maintenance or refurbishment process and expense, and provides a rough estimate of the cost of this intervention.

We would like to present first part of the project that is focused on technologies and procedures for monitoring historic buildings behaviour and present the application of this set of tools in situ on several case studies including on-line monitoring by wireless technologies with possibility of continuous evaluation.

Keywords: structural diagnosis, on-line monitoring, cultural heritage, sustainable management, maintanance

1 INTRODUCTION

Building objects including historical buildings require regular maintenance or major repairs or reconstructions during their lifetime. The purpose of these activities is to ensure the usability of the building throughout its expected lifetime, or even to extend the life of the building. In order to determine the correct remediation action, it is necessary to evaluate the condition of the building. This evaluation is carried out on the basis of building-technical surveys, where various parameters are monitored, such as strength of building materials, size of deformations, degradation of structural elements by various influences (moisture, biological attack), etc. Normative directions are available to evaluate the condition of objects based on the information obtained (ČSN ISO 13822). After evaluating the condition of the building follows the proposal of the remediation method and its implementation. The remediation methods themselves are described in the literature quite abundantly, e. g (Vinař, 2014). However, a fundamental problem for the proposal of a remediation intervention is the discovery of the causes of the unsatisfactory condition of the building structure or element, as well as the prognosis of damage development.

2 PURPOSE OF LONG-TERM MONITORING

Commonly used methods of building construction diagnostics (Hobst, 2005) are aimed at finding out the current status of a building at the time of engineering survey. A one-time survey is usually insufficient to assess the condition and determine any prognosis, the object needs to be monitored over a longer period of time. One year can be considered as a minimum. The purpose is to capture the influence of the outside environment so that all seasons with relevant parameters are covered.

The purpose of monitoring and evaluation itself may vary. The monitoring of the indoor environment parameters is primarily used to assess the suitability of this environment for the placement of various materials, collection items, etc., as well as to evaluate the environmental parameters affecting people, if they occur in the building for a long time, e. g when performing work duties. Last but not least, the monitoring of indoor environment parameters can help to estimate the potential development of damage, estimate lifetime, the need for remediation, etc., which may relate in particular to the construction of wood but also to materials based on paper, fabrics and other natural materials that are stored in interior. In this case, parameters such as temperature, humidity, dew point, etc. can be monitored.

The monitoring of static construction manifestations is then used to detect failures and their development, weakening, overload etc. These observations usually result in a condition assessment, assessment of structural eligibility, residual lifetime, and possibly in the design and planning of remediation intervention. In this case, parameters such as deflections of elements, crack openings, response to dynamic effects, etc. are monitored.

One-time assessment of the state - measurement - will provide an image of the current state of the object, but only a limited one. More information will be provided by a set of measurements performed at intervals over a longer period of time as they can show the dynamics of each parameter. For the simplest tracking procedures, commercially available aids or simple devices are available, and special devices can be used for specific purposes, which are often subject to separate research and development.

3 IMPLEMENTATION OF LONG-TERM OBJECT MONITORING

The simplest option of long-term monitoring is regular repetition of measurements. The disadvantage of this is the necessity of regular on-site visits so the actual implementation is quite time-consuming and only individual discrete values of parameters are obtained. Measuring points must always be properly fixed so that the measurement is always done in one place, otherwise it is difficult to follow the previous values. A certain advantage can be seen in the fact that there is usually no measuring device remaining and thus it can be easily prevented from damage or loss, or simple devices with a low purchase price can be installed, where possible loss does not have a significant negative effect. Perhaps except for the data. The equipment for this tracking is commonly available.

Another possibility is the use of a measuring device that allows the recording of measured data into the internal memory by so-called data loggers. The advantage of this procedure is to obtain continuous recording of values at set time intervals, usually no permanent power supply is required, because the devices are powered by batteries, an on-site visit is only necessary for data collection or battery replacement. The disadvantage is the fact that the data are obtained only in time and cannot be immediately reacted to. Another, not insignificant, disadvantage is the need to leave equipment in place, which can lead to damage or loss. Devices for this tracking procedure exist and are commercially available and can be used without further modification.

The most advantageous for long-term monitoring are assemblies enabling not only short-term recording but also remote data transmission. This can be done in batch or continuously, the data transfer itself can be realized by various means - via the Internet, wirelessly, etc. The data are available immediately after they are obtained, which allows immediate response. E.g. damage to individual measuring elements is immediately apparent and remedies can be made. However, these systems, in particular in the case of long-term monitoring (months to years), require permanent power supply. The data acquisition and processing devices used - data loggers - must be sufficiently resistant to damage. In this case, they are specialized devices that are either not commercially available or are too expensive to use in harsh environments.

4 USED MEASURING DEVICES

Simple measuring instruments with direct operation are used for one time measurements. To measure deformations and crack openings, scales, magnifying glasses or microscopes, indicator watches are used. For temperature measurement contact or non-contact thermometers can be used. Air humidity can be detected by classical hair hygrometers, moisture of materials by using resistance, capacitive or electromagnetic hygrometers.

For long-term measurements that do not require attendance, the basis for monitoring is the creation of a measurement string usually consisting of:

- Sensor of appropriate parameter - deformation, temperature, humidity, vibration, etc. Typically, they are transducers based on the change in resistance for passing electrical current - sensors of deformation, humidity, temperature, sensors inducing voltage on the coil based on the speed of movement, sensors creating electric charge based on the magnitude of acceleration.
- Signal amplifier - the signal obtained by some types of sensors is so low that it needs to be amplified for further processing as well as for longer distance transmission. Sometimes the amplifier can already be built into the sensor.
- Cable data transfer - from sensor or amplifier to switchbox.
- Data transmission for evaluation - internet, cable transmission, wireless transmission.
- Data processing in the office with possibility of continuous monitoring.

In our case, based on the requirements of the cooperating company EMS Pohl, a measuring center, labeled EMS DV 803, was developed, enabling long-term data recording into integrated memory, or on-line data transmission via the internet network or even wirelessly via the GSM module. The control panel can connect up to 32 sensors of different magnitudes - temperatures, deformations, acceleration, voltage or current in general. Due to the sampling frequency of up to 3200 Hz, it can also accommodate dynamic phenomena. The device is functional in the temperature range -20 to +750 °C and can be enclosed in a waterproof case.

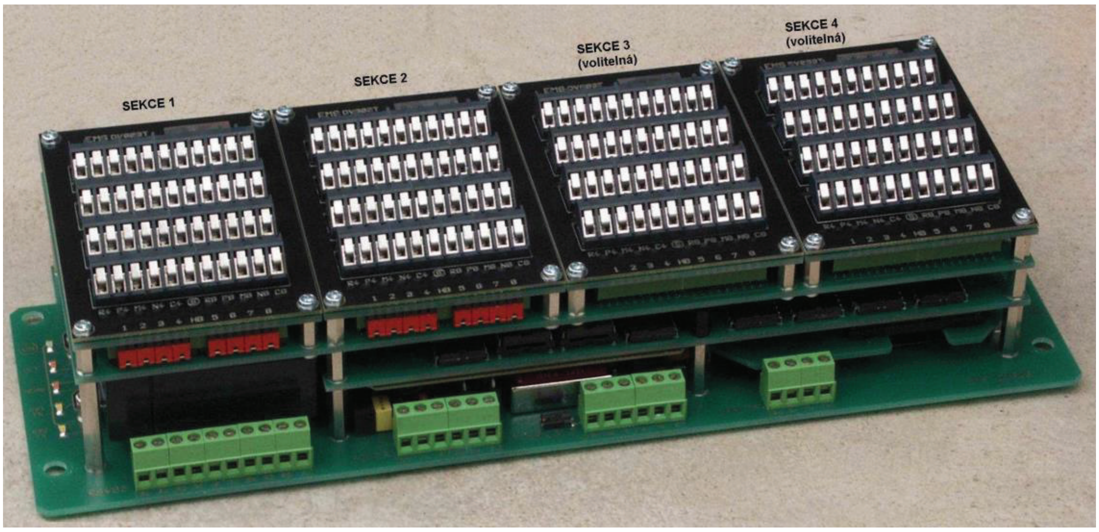

Fig. 1 – measuring center

5 EXAMPLES OF LONG-TERM MONITORING

5.1 *Stability of retaining wall*

First example that is presented is the simplest way to monitor the building structure using simple techniques with the need for regular on-site visits. A brick retaining wall at the foot of the Vítkov Hill in Prague was monitored. The age of the wall is estimated to be at least 100 years, during the last five years, there have been carried out construction and landscaping work at the top to create a bicycle path. These modifications have changed the wall load and the surface water flow. Subsequently, cracks were found in the wall and doubts arose about its stability. (Fig. 2) Subsequently, cracks in the wall were detected and doubts arose about its stability, assuming a relatively demanding remediation, aimed at stiffening and strengthening the entire structure. In order to verify the stability, the crack opening was monitored by means of a permanently installed crack width meter (Fig. 3), together with measuring the outside temperature. Data was read at intervals of approximately 2 weeks. Monitoring is long-term, the result is for the first 7 months.

Fig. 2 – wall with a crack, placement of measuring tool

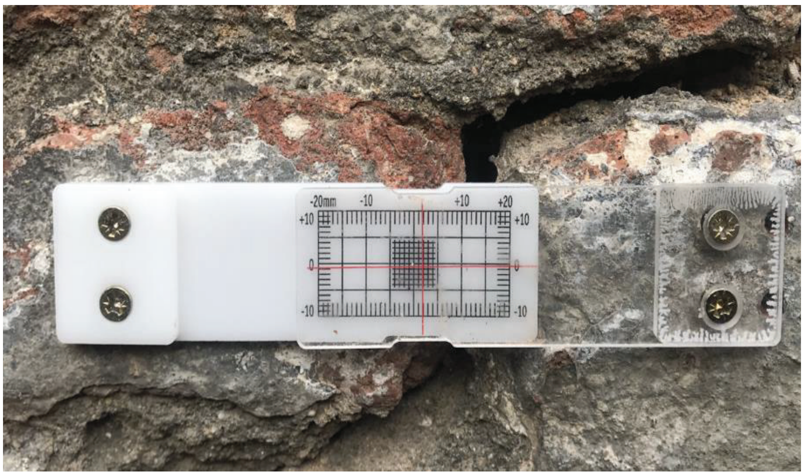

Fig. 3 – measuring tool

The graphical representation of the deformation and temperature change shows a clear dependence of the crack width over the temperature change. The retaining wall itself is evaluated as stable, changes in crack width are caused only by temperature changes (Fig. 4) On the basis of this assessment, the remediation intervention could be canceled and significant costs were saved.

The measurement performed relatively simply, using simple measuring techniques, proved the stability of the retaining wall, where changes in crack width are bound exclusively to temperature changes. The advantage of this procedure is low cost (the purchase price of one meter is around 28 €, the meter is reusable). The disadvantage is the need for regular visits to the operator and the possibility of damage. Possible damage is not detectable until the next data reading.

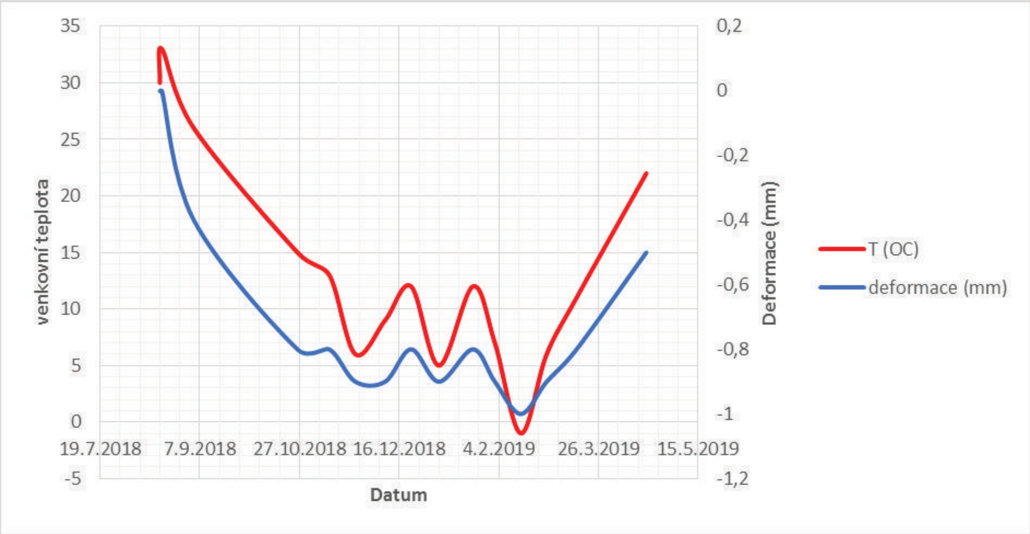

Fig. 4 - Recording of deformation and daily temperature changes

5.2 *Long-term monitoring of the interior microclimate*

This is an example of long-term monitoring where the relevant parameters are recorded in the instrument's memory at regular intervals and need to be read regularly. The purpose of the monitoring was to evaluate the microclimate in the area of the treasury of the Virgin Mary Assumption Church in Kutna Hora (Fig. 5). The measurement itself was carried out during the normal operation of the church with the aim of assessing the internal environment by the treasury and the proposal of possible modification of the operation.

The treasury itself consists of a rectangular space with side lengths of approximately 8,6 x 3,7 m. The cubic space estimate is 115 m3. The room is inside the transept of the nave and is surrounded by other rooms and a staircase from the east. The room itself is connected to the main church by a connecting door and has no separate ventilation. The floor is made of ceramic tiles.

In order to obtain the microclimate and surface temperature values, the Comet 3631 monitoring device was installed in the treasury area approximately 2.8 m above the floor in the room axis. The datalogger was set to measure relative humidity, air temperature and dew point. Data was automatically stored in the device at regular intervals of two hours. Typical measurement results are shown in Fig. 6, which shows the long-term course of ambient temperature, dew point temperature and so-called specific humidity.

Based on these records, it was stated that the specific humidity in the monitored period 10/2017 - 7/2018 ranged between 1.7 g / kg s.v. 12.6 g / kg s.v. in the summer months. The decisive parameter for the long-term preservation of a valuable inventory is a stable specific humidity of 6.5 to 8.9 g / kg s.v. Based on the long-term measurement of the internal microclimate, the natural behavior of the space during normal operation was reliably detected and recorded. The measurement defines the values of the basic parameters (relative air humidity, air temperature and specific air humidity) at each stage of the annual cycle and clearly specifies the limits for exceeding the required values. Thanks to the measurement, the basic requirements for the location and characteristics of the mobile indoor air conditioning unit were specified. The basic parameter for measuring and regulating the treasury environment was the software setting the specific humidity limits to trigger humidification and air drying units to optimize the environment for storing valuable inventory. The measurement and control unit has been developed and fitted as a unique device specifically for the Treasury space.

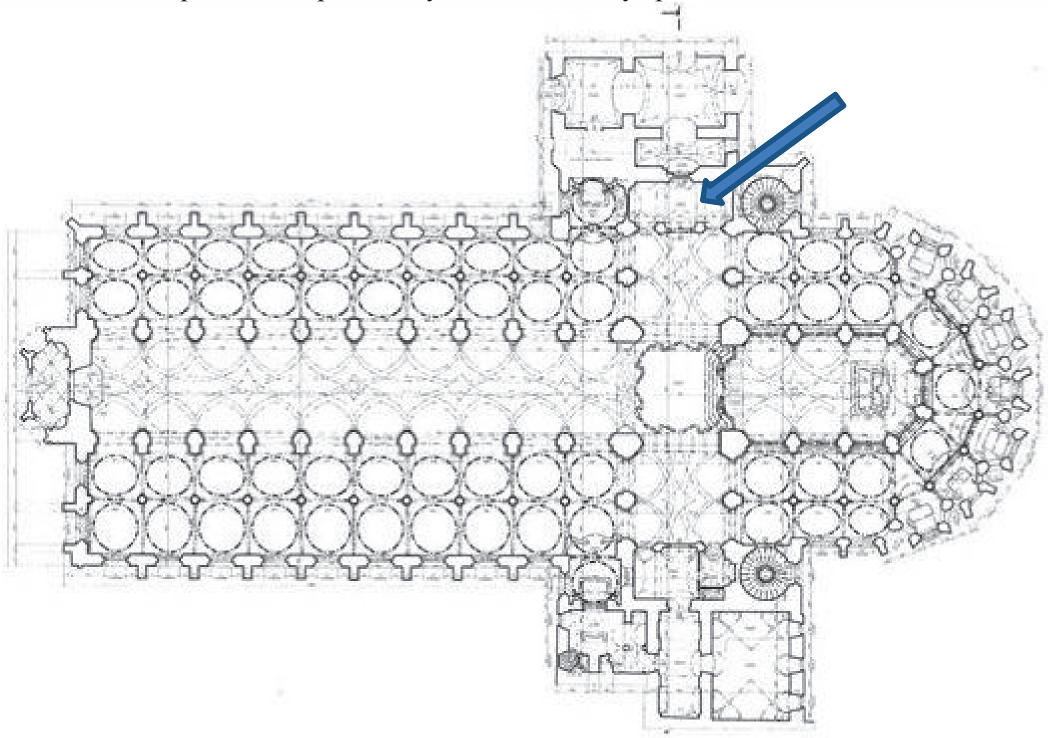

Fig. 5 – placement of the treasury

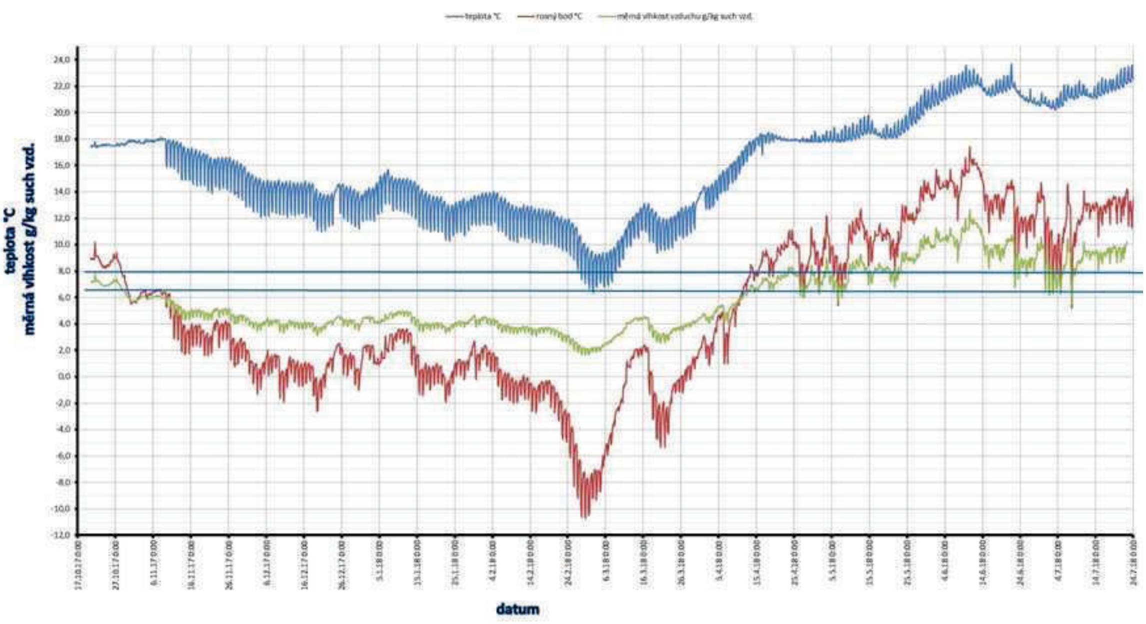

Fig. 6 - recording of data from datalogger

5.3 *Long-term monitoring of an industrial production facility*

During the construction and technical survey of the industrial building from the 19th century, significant cracks were found in the supporting structures, in the ceiling vaults and in the pillars. Again, there were doubts about the static function of the load-bearing structures, with the assumption of reinforcement of the structures and thus costly remediation. A long-term measurement aimed at assessing the development of failures and the possibility of gradual degradation of the building and loss of stability and functionality of load-bearing structures was established to assess the possible development of the failure. A total of 13 potentiometric displacement sensors and four thermoelectric cells for indoor and outdoor temperature monitoring were installed. Approximately 1500 m of cables were installed to transmit data from the sensors. For data processing was used measuring center EMS DV-803, which allows connection of up to 32 pieces of sensors of different kind. The data was permanently available using a GSM modem. The data itself was processed at monthly intervals, however, permanent access to the control panel enabled immediate detection of any anomalies, such as damage to sensors or wiring, which occurred during various building and maintenance activities in the building and the excessive crack opening was immediately detected.

Fig. 7 shows the course of the measured deformations within one month, along with outdoor temperature display. The record shows a clear relationship of the course of the overall deformations over the course of temperatures. At the same time, the influence of day and night time is evident, as is the temperature change during the day.

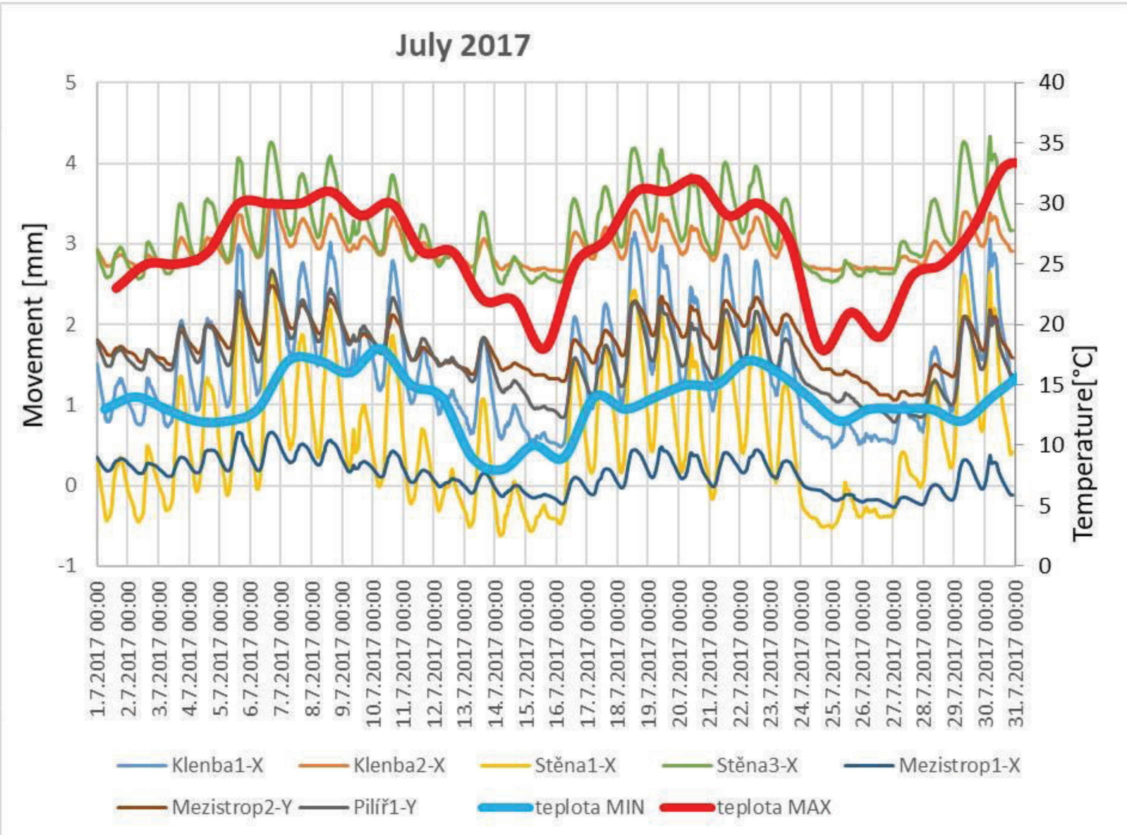

Fig. 7 – monthly record of deformations

Fig. 8 shows the total deformation record in about 2 years. It can be seen that the total deformations are dependent on outdoor temperatures (depending on the season). At the same time, it is clear that the initial and final deformation magnitudes in the individual points are virtually identical.

Based on the evaluation, it was stated that the deformations of individual structural elements are caused solely by outside temperatures, and that they do not enlarge in the long term. Thus, the object was evaluated as stable without the need for static security and thus with significant cost savings.

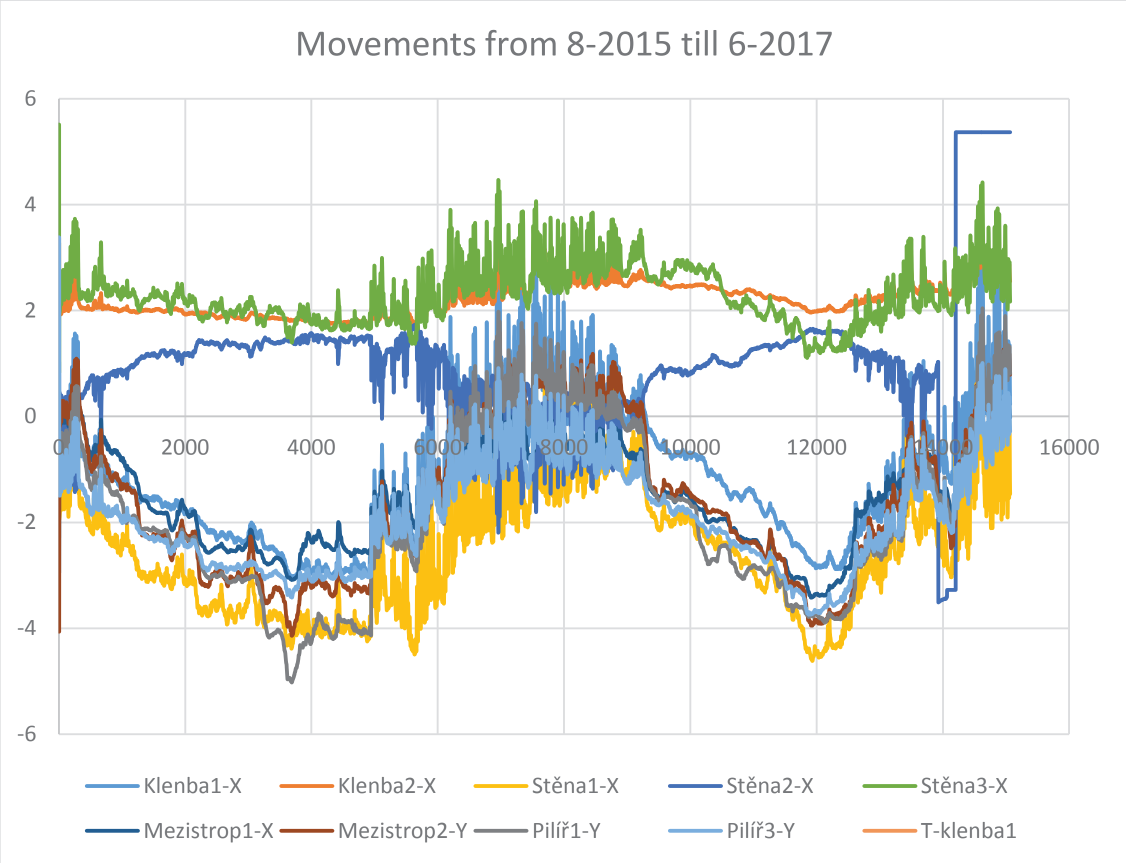

Fig. 8 – course of deformation in 2 years period

6 CONCLUSION

These examples show that long-term monitoring of selected parameters on building sites is justified. It enables to evaluate the building behavior over a longer period of time, to assess the negative effects on the construction, to predict the development possibilities and thus to provide the basis for the possible determination of the residual life, or to suggest remediation interventions.

The form of tracking can then be very different, from simple procedures to minimal costs, to sophisticated solutions, allowing track larger parts of buildings for longer periods, which are more expensive. Thus, the scope and tracking process can be adapted to the requirements of a particular assignment.

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