Temperature and Humidity Conditions of Archives Building under Variable Heat Impacts

I E Molostova¹, S D Vyatkina¹, A S Plotnikov¹, J S Ulyanova¹

¹Federal State Budget Educational Institution of Higher Education “Industrial University of Tyumen”/ IUT, Tyumen, Russia (625001, Tyumen, 2 Lunacharskogo Street

E-mail: molostova1@yandex.ru

Abstract. Temperature and humidity conditions in archives building was considered under variable heat impacts. The experiment was carried out to evaluate the effect of humidity and indoor air temperature on the intensity of building envelopes drying. Experimental data was analyzed with the operating central air conditioner. A method of building envelopes drying by variable heating conditions with simultaneous sorption of moisture from the indoor air was suggested.

1. Introduction

There are lots of archives, museums and galleries in Russia located in buildings of soviet and pre-soviet construction. Due to increased moisture content in building envelopes and increased humidity of indoor air such buildings often have problems with maintaining the temperature and humidity conditions. Temperature and humidity are the basic aspects providing preservation of archive funds. In archives buildings the optimal temperature and humidity conditions are to be maintained for the documents kept in, taking into account the specific features. Apart from that, increased humidity of building envelopes brings additional heat losses of buildings and structures subsequent to the growth of thermal conductivity coefficient of materials. High humidity in building envelopes results in occurrence of biocorrosion, biological damages and contributes to increased humidity of air inside the building. The humidity degree of structures also influences their durability (frost resistance, strength, etc.) [1].

Drying of structures will enable to increase durability of newly built and reconstructed buildings as well as it will enhance their energy efficiency. Moreover, the required temperature and humidity conditions will be provided inside the building which is of great concern for historical buildings and buildings used for preservation and display of exhibit items of historical and cultural heritage of Russia. Drying methods of building envelopes are selected in accordance with some aspects. The methods include: drying with heated air, electric heating, radiator drying, exfiltration drying and drying with high-frequency current, vacuum and electroosmotic drying. However, the methods mentioned above are either energy- and labour-consuming or the structure is dried out just for the insignificant depth.

Authors suggest drying of building envelopes by means of variable heating conditions with simultaneous sorption of moisture from the indoor air of a building.
This method allows intensification of moisture removal not only from the surface layer usually being of 5-7 cm, but also removing moisture from the structure itself carried in during construction and operation of a building. The main point of this method is built upon practical examinations of the natural drying of building envelopes. The practice of buildings operation in the areas with continental climate distinctive with sharp fluctuations in temperature both during the day and during the year prove the drying effect of such variable heating impacts and the dry condition of building envelopes attributed to that [2]. In climatic areas with less temperature fluctuations with all other conditions being equal humidity of building envelopes materials is normally higher. In natural conditions building envelopes are subjected to variable heating conditions depending on varying parameters of indoor and outdoor air [3]. Such a phenomenon is based on the laws of capillary-porous bodies drying, i.e. the laws of moisture motion in liquid and vapour phase in building envelopes. With decrease in the temperature of external surface moisture transfer takes place in liquid and vapour phase from the inner humidified layers of structure towards that surface; with increase in the temperature the transferred moisture evaporates. In case inside the humid material there is a temperature drop then, influenced by temperature gradient, moisture in the form of liquid or vapour moves towards the heat streams to the cold side. One of the reasons of such moisture migration is molecular movement of liquid and vapour, i.e. thermal diffusion. With the temperature increase water surface tension decreases and its surface pressure respectively. In the areas with higher temperature water surface tension is less, volume pressure is larger, and therefore moisture in capillary-porous bodies moves towards lower temperatures. The increase of air volume in capillaries and cavities also contributes to moisture transition inside the heated capillary-porous body; mechanical moisture pushing along the capillaries takes place thereby. At the same time the law of moisture transfer in two phases is applied, the moisture moving from more humidified areas to the areas with the least moisture content and further evaporation to the air environment. Diffusion and capillary displacement laws combine in one law, i.e. moisture conductivity law that can be defined as follows: moisture flow density is directly proportional to the concentration gradient or moisture gradient in the normal direction towards iso-concentric surface [4]. The amount of moisture vapoured is directly proportional to the difference of vapour partial pressure of evaporated liquid at the surface and in the environment, it is directly proportional to time, intensity of moisture diffusion from the volume of building envelope to the evaporation surface [5]. In order to intensify the drying of building envelopes removal of excess moisture from buildings under operation is required to be provided.

For the goal of providing the required conditions inside the building of archives central system of air conditioning operates under variable heating conditions by means of alteration of heating and cooling degree with simultaneous moisture sorption from indoor air. Resulting from that, the values of temperature and humidity of indoor air are stabilized to the regulatory values upon the completion of building envelopes drying process.

2. Objects and Methods
Experimental study was carried out to evaluate the influence of humidity and temperature of indoor air on the intensity of building envelopes drying under variable heating conditions. Experiment was conducted from 4 January to 7 July 2003.

The object of experiment was: State institution “Storage Center of Insurance Fund” in Yalutorovsk city, Russia. The building is four-storey. The total number of premises is 8. Building floor area: - total – 1491.6 m²; - basic – 1081.4 m²; - basement, pits – 410.2 m²; - Architectural volume – 12441 m³.

Design outdoor air temperature in cold season was 38ºC below zero. Design outdoor air temperature in warm season was 28ºC above zero [6,7,8].

Design indoor air temperature was 10ºC above zero and relative air humidity was 55% during the year. Inside the buildings temperature and humidity fluctuations over the established limits are inacceptable (relative humidity ±10%, temperature ±0.5ºC), as it may result in breakdown of archival materials [9].
Central air conditioner CV-A 1P N-592/1-7 [10] and devices to control temperature and humidity of air were used in the present experiment. Humidity of building envelopes was measured by moisture meter VIMS-2.2. Temperature and humidity inside the building was measured using thermometer and hygrometer. Dry-and-wet-bulb hygrometer was installed inside the room, consisting of two thermometers: dry and wet. All equipment has undergone verification. Schematic diagram of experimental setup is shown in Figure 1.

**Figure 1.** Schematic diagram of experimental setup.

1– supply duct; 2– feed section; 3– first cooling section; 4– heating section; 5– fan unit; 6– second cooling section; 7– noise suppressor; 8– hygrometer; 9– thermometer; 10– return air duct; 11– dry-bulb thermometer; 12– wet-bulb thermometer.

During the experiment the following readings were recorded: dry-bulb thermometer temperature, wet-bulb thermometer temperature, relative air humidity inside the building. The readings were taken from 4 January 2003 to 7 July 2003.

The obtained data was processed as follows:
Cold consumption for the air cooling was calculated according to the following equation:

\[
Q_{\text{cool}} = G_s (J_1 - J_0),
\]

(1)

where \(G_s\) – air supply volume, kg/h.
\(J_1\) - enthalpy of air before cooling section, kJ/kg;
\(J_0\) - enthalpy of air after cooling section, kJ/kg.
Moisture content condensed on the surface of heat exchanger was determined as in:

\[
W_c = G_s (d_i - d_f) \cdot 10^{-3},
\]

(2)

\(d_i\) - moisture content of air before cooling section, g/kg;
\(d_f\) - moisture content of air after cooling section, g/kg.
Table 1. Results of measurements.

| Date     | t dry | t wet | rel. hum. | t dry | t wet | rel. hum. | t dry | t wet | rel. hum. | t dry | t wet | rel. hum. | t dry | t wet | rel. hum. |
|----------|-------|-------|-----------|-------|-------|-----------|-------|-------|-----------|-------|-------|-----------|-------|-------|-----------|
| 01.04.03 | 9.5   | 5     | 4.5       | 46    | 10.5  | 9.5       | 46    | 13.5  | 7        | 38    | 10    | 5.5       | 44    |       |           |
| 03.04.03 | 9.5   | 5     | 4.5       | 46    | 10.5  | 9.5       | 46    | 13.5  | 7        | 38    | 10    | 5.5       | 44    |       |           |
| 05.04.03 | 9.5   | 5     | 4.5       | 46    | 10.5  | 9.5       | 46    | 13.5  | 7        | 38    | 10    | 5.5       | 44    |       |           |
| 07.04.03 | 9.5   | 5     | 4.5       | 46    | 10.5  | 9.5       | 46    | 13.5  | 7        | 38    | 10    | 5.5       | 44    |       |           |

Note: The table continues with similar data entries.
14.04.03 10 6 57 10.5 6.5 57 11 7 58 17 10 39 10.5 6.5 57
15.04.03 10 6 57 10.5 6.5 57 10.5 6.5 57 16.5 10 42 11 7 58
16.04.03 11 7 58 11.5 7.5 58 10.5 7 62 16 10 45 11 7 58
17.04.03 11 7 58 11.5 7.5 58 11 7.5 62 15.5 10 48 11 7 58
18.04.03 11.5 8 62 12 8 58 12 8.5 63 15.5 10 48 12 8.5 64
28.04.03 14.5 10 56 15 10 51 15.5 10.5 54 18 11.5 45 15.5 10.5 54
29.04.03 13.5 8 46 14 8 43 14 8 43 16 9 39 14 8 43
30.04.03 13.5 8 46 14 8 43 14 8 43 16.5 9 35 14 8 43
02.05.03 12 9 61 13 9 61 13 9 61 16 10.5 49 13.5 9.5 60
06.05.03 13 9 61 13 9 61 13 9 61 16 10.5 49 13.5 9.5 60
07.05.03 12.5 9 65 13 9 61 13 9 61 16 11 55 12 9 70
08.05.03 13 9.5 65 13 9.5 65 13.5 9.5 60 16.5 11 50 13 9.5 65
12.05.03 14 12 80 14 12 80 15 12 71 17 13 64 15 12 71
13.05.03 15 12 71 14 12 80 15 12 71 17 13 64 15 12 71
14.05.03 14.5 12.5 80 14.5 12.5 80 15 12.5 76 16.5 13 67 15 12.5 76
15.05.03 14 11 70 14 11 70 14 11 70 15.5 11.5 62 14 11 70
26.05.03 13 10.5 74 14 11 70 15 11 63 17 12 56 15 11 63
27.05.03 13 10 69 13 10 69 14 10 60 15 10.5 57 14 10 60
28.05.03 13 9.5 65 12.5 9 65 13 9 61 15 10 52 13 9 61
29.05.03 12.5 9 65 12.5 9 65 13 9 61 14.5 9.5 52 13 9 61
30.05.03 12.5 9.5 68 12 9 70 12.5 9 66 14 10 60 12.5 9.5 68
02.06.03 12 9 70 11.5 8.5 69 11.5 8.5 69 73 9.5 66 12 9 70
03.06.03 12 9.5 74 12 9.5 74 12 9.5 74 13.5 10 66 12 9.5 74
04.06.03 12 9.5 74 12 10 78 12.5 9.5 70 15 11 62 12.5 9.5 70

3. Results discussion
The data on temperature and humidity conditions in archives buildings was processed and analyzed using I-d diagram [4,10] along with the modes of air conditioner operation from January to July 2003 and the following results were obtained.

The average temperature in January [11] in archives buildings with the central air conditioner operating under variable heating conditions reached 11°C, relative humidity stayed within the range of 53% [12], which is within the acceptable range of fluctuations of relative humidity ±10 % for such kinds of premises. However, temperature fluctuations went beyond the scope of the given value of acceptable fluctuations ±0.5°C.

The average temperature in February in archives buildings was 10°C; relative humidity was 48%, which was within the regulatory indoor parameters. From 31 January to 3 February 2003 the temperature increased by 1±1.5°C. Cooling section was on, leading to decrease in temperature and relative humidity of archives up to the regulatory value. At the same time during 13 days (5-18 February) sorption of moisture from the air occurred in the amount of $W = 60$ kg of water. Cold consumption $Q= 12$ kW. After turning the cooling section off and turning the heating section on, temperature and moisture content of indoor air grew by 1 g/kg of air [13, 14].

The average temperature in March in archives buildings was 10.9°C; relative humidity was 50.5%, which lies within the acceptable range of fluctuations of relative humidity ±10 % for this kind of buildings. At the same time temperature fluctuations went beyond the given value of acceptable fluctuations ±0.5°C. In the period of 24-28 March cooling section was on [15]. Cold consumption $Q = 15.6$ kW. Removal of moisture from indoor air by sorption took place in the amount of $W = 37.2$ kg. Consequently, using variable heating conditions while operation of central air conditioning system temperature fluctuations inside archives buildings were 1±1.5°C, moisture content decreased by 0.5±1 g/kg, relative humidity varied within 52÷58 %.

From 1 to 21 April 2003 growth in temperature and moisture content was observed up to 6 g/kg at fluctuations of relative humidity by 5%, which is unacceptable by regulatory requirements.
The average temperature in May and June while operation of central air conditioner under variable heating conditions was 13.2°C, φ = 68 %. These parameters of indoor air exceeded the regulatory ones significantly. The air inside buildings was moisture-saturated; condensate dropout took place on the cold surfaces [16,17]. Intensive moisture sorption from indoor air occurred. Only during 20 June by means of sorption W = 63.3 kg of moisture was removed. Cold consumption in this case was Q= 31.3 kW.

During the half-year period considered in the present study systematic growth of relative humidity of air and its moisture content took place, in spite of a significant moisture sorption by air conditioner. For instance, on 2 June 2003 W = 28.8 kg was dropped off; on 6 June 2003 –W= 60 kg; on 17 June 2003 –W= 28 kg [18].

The phenomena considered above are tied to the thermodiffusion effect in building envelopes causing intensive drying of building materials that building envelope consist of, with further moisture evaporation into indoor air of a building and sorption from it when using central air conditioner. Upon the experiment completion moisture meter was used for the control measurement of moisture not destructing the building envelope. Moisture level of building envelope did not exceed the acceptable ones of 4%.

When building envelopes reached the regulatory humidity, temperature and indoor air humidity inside the archives buildings were stabilized at the required regulatory values with the acceptable value fluctuations in temperature and humidity for this category of buildings [18,19].

4. Conclusion

The following conclusions were made upon the results of a given experiment.

Creating optimal conditions for preservation of documents in archives buildings needed installation of air conditioner, providing control of temperature and humidity and operating under variable heating conditions during the whole period of study. Relative humidity of indoor air and its moisture content was gradually growing inside archives buildings due to intensive moisture evaporation from the internal surface of building envelopes despite the significant moisture sorption from the indoor air by air conditioner [20]. The amount of hygroscopic water varied from 28 to 63.6 kg, refrigerating power of air conditioner varied from 0.7 to 31.3 kW.

By the end of experiment this enabled to stabilize temperature and humidity parameters of indoor air inside archives to the regulatory values, after completion of building envelopes drying the humidity value was stabilized at the regulatory value not exceeding 4%.

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