Forecasting of the group of power system’s technical condition composite index and demand for heat energy by office buildings using an artificial neural network

S V Guzhov, T Y Andreeva and A P Sofronitsky
Department of Heat and Mass Transfer Processes and Installations, National Research University MPEI, Krasnokazarmennaya St., 14, Moscow, 111250, Russia

E-mail: GuzhovSV@yandex.ru

Abstract. Support of a sustained reduction of energy resource consumption by implementing advanced energy-efficient technologies, including alternative and renewable energy sources, requires a well-reasoned selection of the cost-effective measures so it can be replicated at the «green construction» sites. One of the basic approaches in forming of the present-day policy in the ecofriendly and energy-saving trends became a scaling effect of what has been achieved from the «green construction» technologies implementation at similar sites in Moscow. The actuality and scientific novelty of this paper lie in the development of the evaluation algorithm of energy and as a result of eco-economic efficiency of different measures for energy-saving, the adaptation of the forecasting methodology for building's technical condition index application, review of the alternative and renewable energy source technologies implementation at the «green construction» sites in the Moscow region, analysis of the technical and ecological efficiency actual values of the utilized energy-saving methods and technologies. Monitoring and dispatching of a large number of separate power plants require special ways of collecting, processing, and analyzing information about the condition of water, heat, fuel, and electricity supply systems to ensure reliability and stability of the equipment functioning. Failures necessitate maintenance works at facilities by way of equipment repair as well as replacement. The consumers may impose penalties on the heat supply company for violating heat energy supply obligations as well as on the building's owner for incorrect equipment maintenance. The objective of this paper is to determine an approach that helps to develop a software program, based on the neural network programming, to calculate the forecasting composite index of building's energy system, «green construction» facilities ecological and economic efficiency examination and feasibility evaluation of their further replication in Moscow region.

Keywords: composite index of technical condition, energy efficiency, renewable energy sources, green construction, software product, deterministic approach, statistical analysis, artificial neural network, office building, forecasting, demand for heat energy, heat energy consumption specific value.

1. Introduction
In order to improve the reliability of the heat substations and heat networks equipment a set of administrative and technical measures has been implemented:

- technical diagnosis and equipment examination including safety review procedure;
- record-keeping of the heat supply system damages;
- development, approval, and fulfillment of the repair schedules;
• maintaining a ledger of the finished repairs that restore performance characteristics during upgrading, modernization, project's capital construction;
• pipeline internal metal corrosion rate monitoring;
• different tests of heat supply networks;
• back-up of crucial equipment and networks;
• outdated equipment replacement.

Since equipment of heat substations and networks inside buildings are commonly available then collection, generalization, and evaluation of data on their current technical status and working conditions is a vital task for the group of similar buildings in Moscow agglomeration [1]. Monitoring should be done in relation to the reliability indexes and functioning stability of main and supporting equipment as long as the routine maintenance is done on a regular basis.

Most foreign information sources focused on the condition index and don't take into account the technical condition. The equipment could be new but without proper maintenance, it will work with parameters deviation. On the other hand, worn-out equipment in a skilled hand can be reliable and effective. The heat supply specific is in fact that preparation for the heating season in Moscow is quite long and usually takes up to 5 months. Quality of this preparation and the following work of stuff is as important as equipment's upgrade; therefore, the index of performance quality should be taken into consideration.

The «green construction» facilities include buildings that have certificates from international systems such as BREEAM, LEED, DGNB, and so on. A total of 195 buildings have been analyzed (Figure 1).

![Figure 1. Structure of green buildings in Moscow.](image)

The selected and analyzed facilities are mostly modern, recently built or redeveloped buildings and facilities that are originally designed and built with reference to [2, 3]:
• eco-management requirements;
• selection of suitable site and infrastructure;
• orientation toward sustainable use of water;
• selection of architectural and engineering designs to optimize lighting, minimize local heating and so on;
• implementation of energy conservation equipment and energy-efficient technologies that ensure environmental safety [4];
• use of eco-friendly construction and finishing materials, the possibility of separate waste collection;
• providing living environmental comfort and so on.

The preliminary data analysis allowed to select facilities that have installed alternative and renewable energy sources. Solar panels and photovoltaic cells [5] are installed at 33 facilities (Figure 2). The number of facilities that utilize new and renewable energy sources (NRES) is presented in Figure 3.
2. Materials and Methods

Generally speaking, energy conservation measures in the system of electrical power equipment of an office building [6] can include (Figure 4):

a) rpm control for engines with unbalanced load;

b) units for reactive power compensation;

c) units for normalization of electrical power quality indexes;

d) replacement of equipment for electrothermal food heating, snow melting, supply air heating, pavement, and floor heating, and so on for equipment with alternative operating principle;

In the electrical lighting system:

a) sources of light with a luminous efficacy of no less than 100 lm/W;

b) automation of electrical lighting systems;

c) installation of solar tubes and optical fibers in the Moscow region can save 30-70% of electric power that is used for artificial lighting.

Figure 2. Facilities which utilize solar sources of heat and electricity.

Figure 3. Number of facilities which utilize NRES.

Figure 4. Composition and contribution of technologies that save an electrical power.
In the heat supply system (Figure 5):
   a) automated terminals for measurement and control of the heat transfer agent temperature in the heating system or individual heat substations;
   b) units for exhaust air low-grade heat utilization;
   c) «air-to-air» heat pumps including with an intermediate heat transfer agent.

![Figure 5. Composition and contribution of technologies that save heat energy.](image)

In the water supply and sewerage systems (Figure 6):
   a) effective water intake equipment which allows saving 15-20% of water resources;
   b) push faucets for handwashing facilities and sensors for urinals which decrease water consumption by 4-6 times;
   c) faucet aerators which allow to save water flow up to 6 l/min and decrease consumption of cold water for 30-35%, hot – for 15-20%;
   d) contact-free faucets and so on.

![Figure 6. Composition and contribution of technologies that save water resources.](image)

The conducted analysis clearly demonstrated a considerable variety of energy saving measures. Buildings have different functional use which means that one type of energy-saving measure gives different outcomes for different building types and sizes even of the same type. Therefore, for the building that is already in operation and had been constructed with specific energy-saving features, it is very difficult to pinpoint a part that provides savings using already implemented measures. Moreover, the operational facility doesn't allow to conduct completely controlled experiments. From this per-
spective, the only possible way is a deterministic approach that utilizes retrospective statistical data on a building's condition from its previous history.

This paper suggests the assessment process of the composite index of technical condition (CITC) of the technological equipment at the being examined facilities conduct according to the Order of the Ministry of Energy of the Russian Federation of 26.07.2017 No. 676. The equipment's technical condition assessment is conducted by comparison of the actual parameter values of the component's technical condition against the maximum allowable values, and also compliance with the requirements that are stated by the regulatory and technical documentation and (or) design (project) documentation of the manufacturers and then CITC of the components and equipment determination in general [7].

CITC can take values on a 100-point scale, where 0 – the lowest value, 100 – is the best value. The ITC calculation is done by the formula:

$$\text{ITC} = \frac{\sum (P_i \cdot \text{ITC}_i)}{\sum (P_i)}$$

where:
- $\text{ITC}_i$ – ITC for i-th equipment;
- $P_i$ – heat capacity of the equipment.

ITC determination for i-th equipment can be done by the empirical method. The conducted calculations demonstrate a possibility of automated calculations by using software which will allow calculating the forecasting composite index of technical condition with the accuracy of no less than 80%, the number of learning rates no more than 200, training time no more than 90 seconds.

Since equipment of heat substations and networks inside the building are commonly available then collection, generalization, and evaluation of data on the current technical status and working conditions is a vital task for a group of similar buildings in Moscow agglomeration. Monitoring should be done in relation to reliability indexes [8], efficiency and functioning stability of main and supporting equipment as long as the routine maintenance is done on a regular basis. Forecast of the CITC value change (Figure 7), during the transition from the current state (point 1) to the forecasted (point 2), should be done considering a change of all three scales: efficiency [9-11], reliability, stability.

![Figure 7. Model of CITC change forecasting.](image)

For the office buildings which were constructed using an individual design or based on a significantly repurposed building, for example, from an industrial to office, calculation of the saving that was achieved from implementation at the construction or operation phase is a difficult and multifaceted problem. Let's take a look at the group of buildings that owns JCS «O1 Standard».

The analysis of an energy-saving equipment implementation that results in increased energy resource utilization efficiency, decreased environmental impact [12] and improved comfort in buildings showed the following. At the facilities certified to the international standards the most common measures are:
Energy saving in the heat supply systems:

1) heating system independent with IHS [13]. Mainly hot-air-heating with recuperation and preliminary air preparation. The northern side of the building is heated by the radiator hot water heating (for example, for the office building Ducat Palace 3), power of which is 15-20% of the whole heating. The rest of the load is covered by the underfloor water convectors (for the office building Lighthouse);

2) the ventilation system is general by using supply and exhaust units with heating from IHS and cooling by chillers with mechanical initiation;

3) the air conditioning system is central with chillers. Ducat Palace 3 office building uses the air cooler;

4) the building uses a general system of heat from exhaust air utilization. Some supply and exhaust units are using a system of recuperation with intermediate heat medium;

5) parking lot exhaust system is combined with the degassing system and made with zone intake and activated by the car exhaust gases;

6) parking lot heating is done by the supply air heating;

7) high-efficiency insulation of the air ducts and pipelines to minimize heat exchange with the environment;

8) use of the air conditioning system which controls the temperature in rooms individually;

9) use of the «Freecooling» system for air conditioning utilizing refrigeration units;

10) use of individual controllers which optimize heat consumption for room heating and ventilation;

11) for the purpose of utilizing sun radiation in building's heat balance the translucent enclosing structures are made translucent with increased heat-shielding values.

12) Energy-saving methods for light pollution reduction:

13) lighting equipment shouldn't be pointed toward the window;

14) street lamps installed along the building's front side and in the surrounding area have reflectors pointed down;

15) every leaseholder uses window blinds of a certain model so the light doesn't radiate outside during evening and night time.

16) Methods for energy consumption reduction:

17) it is necessary to use LED light sources with a color temperature of 4000 K or similar fluorescent lamps;

18) where safety rules allow the internal doors and non-load bearing enclosing structures in buildings should be made of translucent materials to use natural light as much as possible;

19) it is necessary to use at the building's reception desks and in the rooms of every leaseholder at least one lamp that is on all the time which allows to partially dim the corridor lights considering the presence of the translucent doors;

20) general lighting at the front desk during the off hours (from 8 p.m. to 7 a.m.) should be off;

21) the outside facade lighting at the office center White Stone had been removed;

22) the outdoor and indoor lighting, except lights to assist moving cars, facade lighting, emergency lights, can be automatically shut down by the lighting automatic control software;

23) the non-essential rooms and corridors have motion and presence detectors and also dusk-to-dawn sensors installed;

24) some supply and exhaust air systems have the rpm frequency control installed on the fan's electric motors (office center iCUBE);

25) installation of the electric power recuperation systems in the elevators;

26) implementation of the elevator's movement rationalization system.

27) Methods for water consumption reduction:

28) toilets are equipped with the dual-flush system: less than 6 l (large flush) and less than 3 l (small flush);

29) public bathrooms have aerators installed in the faucets which limit flow rate: for example, less the 5 l/min (kitchen faucet) and less than 4,5 l/min (bathroom faucet);

30) urinals which don't require flush after every use or with limited flow rate, less than 0,3 l/sec;
31) use of showerheads with a flow rate of less than 6 l/min;
32) installation of technical record-keeping equipment at the leaseholders and also at the consumers that have high water consumption;
33) dishwashing machines with a flow rate of less than 13 l per cycle;
34) washing machines with a flow rate of less than 40 l per cycle;
35) rainwater is not used for watering of plants on the surrounding territory;
36) automatic disablers of water flow in bathrooms are installed.
37) Waste collection:
38) availability of separate waste collection inside the building and nearby, availability of electric batteries collection, waste compactor, availability of the medical waste collection in view of the pandemic;
39) implementation of condenser water collection system;
40) the building lacks a snow melting system that works from the inhouse heat emitters such as chiller exhausts, general ventilation, sewage pipelines, and so on;
41) the building lacks a waste treatment system and equipment for industrial water reuse;
42) advanced building management systems (BMS) with a high level of automation had been implemented in the building: control of temperature, humidity, and CO2 content in the inhouse air.

From the point of view of the acting regulatory documentation on the engineering of a new or under reconstruction buildings, there are approved specific values of energy consumption on which the design documentation development is based (Table 1).

### Table 1. Regulatory specific values of the consumed electrical energy, heat energy, and water resources in Moscow city.

| No | Index of specific values | Value |
|----|--------------------------|-------|
| 1. | kW/sq m (RD 34.20.185-94) | 0.109 |
| 2. | kW/per person (RD 34.20.185-94) | ~0.270 |
| 3. | kW/per flat (РД 34.20.185-94) | 0.620125 |
| 4. | For a single person living in a flat with a gas stove, kWh/per person (Moscow GD of 20.12.1994 N 1161) | 50 |
| 5. | For a single person living in a flat with an electrical stove, kWh/per person (Moscow GD of 20.12.1994 N 1161) | 80 |
| 6. | For a family living in a flat with a gas stove, kWh/per person (Moscow GD of 20.12.1994 N 1161) | 45 |
| 7. | For a family living in a flat with an electrical stove, kWh/per person (Moscow GD of 20.12.1994 N 1161) | 70 |
| 8. | Heat energy consumption norm for housing unit heating, Gcal for total sq m of housing | 0.016 |
| 9. | Heat energy consumption norm for water heating | 0.294 |
| 10. | Building's specific annual heat consumption norm, Gcal annually/sq m | 0.192 |
| 11. | Apartment hotels with water supply system, gas, and hot water system, m³/l person per month. | 7.31 |
| 12. | Apartment building with water supply system, wastewater system, gas pipeline, and no bathtub, m³/l person per month. | 4.57 |
| 13. | Water consumption for plant watering at the home garden during the growing season: May-September, 153 days, 18 waterings per month, m³/sq m | 0.16 |
| 14. | Floor cleaning in the administrative and public buildings, l/per sq m per cleaning | 2.40 |
| 15. | Administrative buildings and rooms considering working hours at least 235 days per year, l/1 working day | 28 |
The examined in this paper office centers: Lighthouse, Ducat Palace 3, White Stone, Silver City, iCUBE are owned by one managing company and constructed considering a unified approach to the implemented technologies [14]. Therefore, one can say that energy systems and subsystems have an adequate degree of similarity properties and can be combined into one group. In such a case, it becomes possible to form a unified artificial neural network (ANN) based on similarity properties [15] of buildings under examination. Trained ANN will allow formulating energy resources forecasting demand for energy systems of the buildings.

3. Results
The forecasting factor (Y) is a heat energy consumption by a subject which is the office building, Gcal. Climate data: average monthly outside temperature, °C; average monthly air humidity, %, - obtained from the public database. For the training purpose has been chosen a three-layer artificial neural network with 4 input neuron layers and 1 output layer, the hidden layer consists of 20 neurons. The activation function has a sigmoid shape with curvature 2.

In the capacity of the training set the following measures have been taken such as heat, electricity, and water consumption at the office centers Lighthouse, Ducat Palace 3, iCUBE from January 2016 to July 2020. A total of 684 units of primary information had been used for ANN training. In the capacity of the test set the following data have been taken such as heat, electricity, and water consumption at the office center Krugozor from January 2016 to July 2019. The total number is 220 units of information. Subjects of comparison are the forecasting and actual heat consumption from August 2019 to July 2020.

4. Discussion
Training of the artificial neuron network took 200 epochs, the maximum error is 0.17565, mean error – 0.019673 (Figure 8).

Results of forecasting which was realized on the training set showed a deviation of the forecasted value from the actual which equals 19.02%; on the test set – 28.65% (Figure 9).

Based on the conducted calculations it is possible to make a conclusion that the forecasted heat consumption values during the heating season are close to the actual heat consumption values considering the lower bound of the calculated value errors. Most of the forecasted value deviations from the actual can be observed during the summer season which tells us that the model is quite accurate in terms of forecasting heat consumption by the building's heating system and availability of an additional potential to improve calculation accuracy of heat energy consumption for hot water supply system needs. In spite of error presence, the forecasting function demonstrates entirely sufficient accuracy for further use in forecasting.
Figure 9. Results of the energy consumption forecasting at the office center Krugozor.

Figure 10. Comparison results of the annual specific values of heat energy consumption by the office center Krugozor:

1. Normative heat consumption = 0.192, Gcal/sq m per year;
2. Actual heat consumption, Gcal/sq m per year;
3. Forecasted heat consumption = 0.087, Gcal/sq m per year;
4. Heat consumption calculated by the Ermolaev formula = 0.087, Gcal/sq m per year.

As an example of the achieved heat energy saving determination can serve a comparison of the annual actual specific values of the obtained energy consumption values with the calculated and forecasted values (Figure 10).

5. Conclusion
This paper presents the conducted analysis and shows the structure of the operated «green construction» facilities in Moscow. It has been demonstrated that 40% of all facilities with implemented green technologies are office buildings.

The paper suggests the algorithm of energy efficiency evaluation of implemented at the facility energy-saving group of measures. The results of algorithm implementation allow to conduct a comparison of the annual specific heat energy consumption values, obtained using the actual and regulatory values, and also based on the consolidated deterministic calculations.

The paper demonstrated the applicability of methodology for calculating the current and forecasted building's index of technical condition for the considered group of problems. Automation of calculation by using the software will allow to calculate the forecasting composite index of technical condition with the accuracy of no less than 80%, the number of learning levels no more than 200, training time no more than 90 seconds.
The ANN model of energy-efficient green building was formulated. Application of this model by way of approximation on any office type building will allow to obtain forecasting results which demonstrate how the energy consumption of the building changes after its upgrade considering implementation of mentioned above energy-saving technologies. The results of forecasting which was realized on the training set showed a deviation of the forecasted value from actual which equals 19.02%, on the test set – 28.65%.

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