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COMPARATIVE SIMULATION STUDIES OF ENERGY CONSUMPTION IN POTATO STORAGE

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Key words: microcomputer simulation potato storage, algorithms for ventilation.

Models applied in microcomputer simulation of potato storage are described, and possibilities of saving energy by selecting suitable control algorithms for ventilation are examined.

INTRODUCTION

Potato storage may require various amounts of energy, depending on the kind parameters of storage as well as on the air-conditioning, ventilation and control systems used. The least amount of energy is of course required by storage systems with natural ventilation using outdoor air only and depending significantly on the weather. However, the use of natural ventilation alone in the climatic conditions prevailing in Poland may lead to substantial potato losses. Air-conditioned storage systems operate regardless of the weather but they consume large amounts of energy. Energy consumption may be reduced by applying suitable storage systems with mechanical ventilation (either exclusively mechanical or combined with natural ventilation) backed up by adequate automated control systems. The mechanical ventilation systems either may or may not mix outdoor and indoor air. In the former case the ventilation system may function in a broader range of climatic conditions. Air streams may be controlled either continously or discretely, with the discrete control systems usually being simpler. Various control algorithms characterized by different energy consumptions may be employed in these systems, and the optimal ones may be selected by comprative simulation studies. This paper describes models used in a program of microcomputer simulation of discretely controlled mechanical ventilation systems capable of mixing outdoor and indoor air.

STORAGE SYSTEM

A scheme of the considered storage system is shown in Fig. 1. During storage, potatoes respire, generating heat and giving off water vapour. Each potato sort

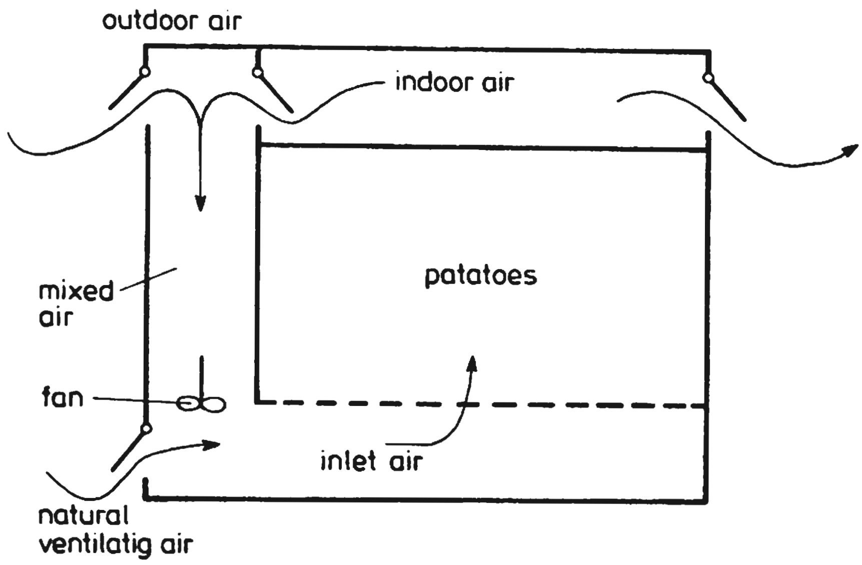

Fig. 1. Scheme of storage with a mechanical-natural ventilation system capable of mixing indoor and outdoor air

has its own temperature range in which heat generation intensity is very low and in which excellent quality of potatoes may be maintained. The ventilation systems must satisfy the following technological requirements: 1) the temperature of potatoes and of indoor air must remain in a given range, and 2) the temperature of inlet air (which may be either outdoor or mixed) ought to remain in a given range, being at the same time several degrees lower than the temperature of potatoes.

DYNAMIC MODEL OF THE STORAGE SYSTEM

There is no need to consider mass exchange in studies of energy consumption during storage, and so the proposed model of potato storage takes into account only heat exchange relations. The heat generated by the potatoes may be accumulated in the potatoes themselves (zk), the outdoor air (pw) and in the walls of the store-house (sk). The structure of heat fluxes between these bodies and the outdoor air depends on the ventilation regime. It is useful to distinguish four such regimes: regime without ventilation (kob = 1), regime with outdoor air ventilation (kpz = 1), regime with indoor air ventilation (kpw = 1), and regime with mixed air ventilation (kpm = 1). The heat flux structures characteristic of the various regimes are shown in Fig. 2. The energy equilibrium equations for these structrures take the form of a system of first order differential equations:

$$
\begin{aligned}
\text{d tpw/dc} = {} & \text{(tsk-tpw)/Tws1} \; + \\
& + \text{(kob+kpz+kpm)} \times \text{(tzk-tpw)/Twk1} \; + \\
& + \text{kpz} \times \text{(tpz-tpw)/Twz1} \; + \\
& + \text{kpm} \times \text{(tpm-tpw)/Twm1} \; + \\
& + \text{kpw} \times \text{(tzk-tpw)/Twk2}
\end{aligned}
$$

$$
\begin{aligned}
\text{d tzk/dc} = {} & \text{(tsk-tzk)/Tks1} + \text{kkx} \; + \\
& + \text{kob} \times \text{(tpw-tzk)/Tkw1} \; + \\
& + \text{kpz} \times \text{(tpz-tzk)/Tkz1} \; + \\
& + \text{kpm} \times \text{(tpm-tzk)/Tkm1} \; +
\end{aligned}
$$

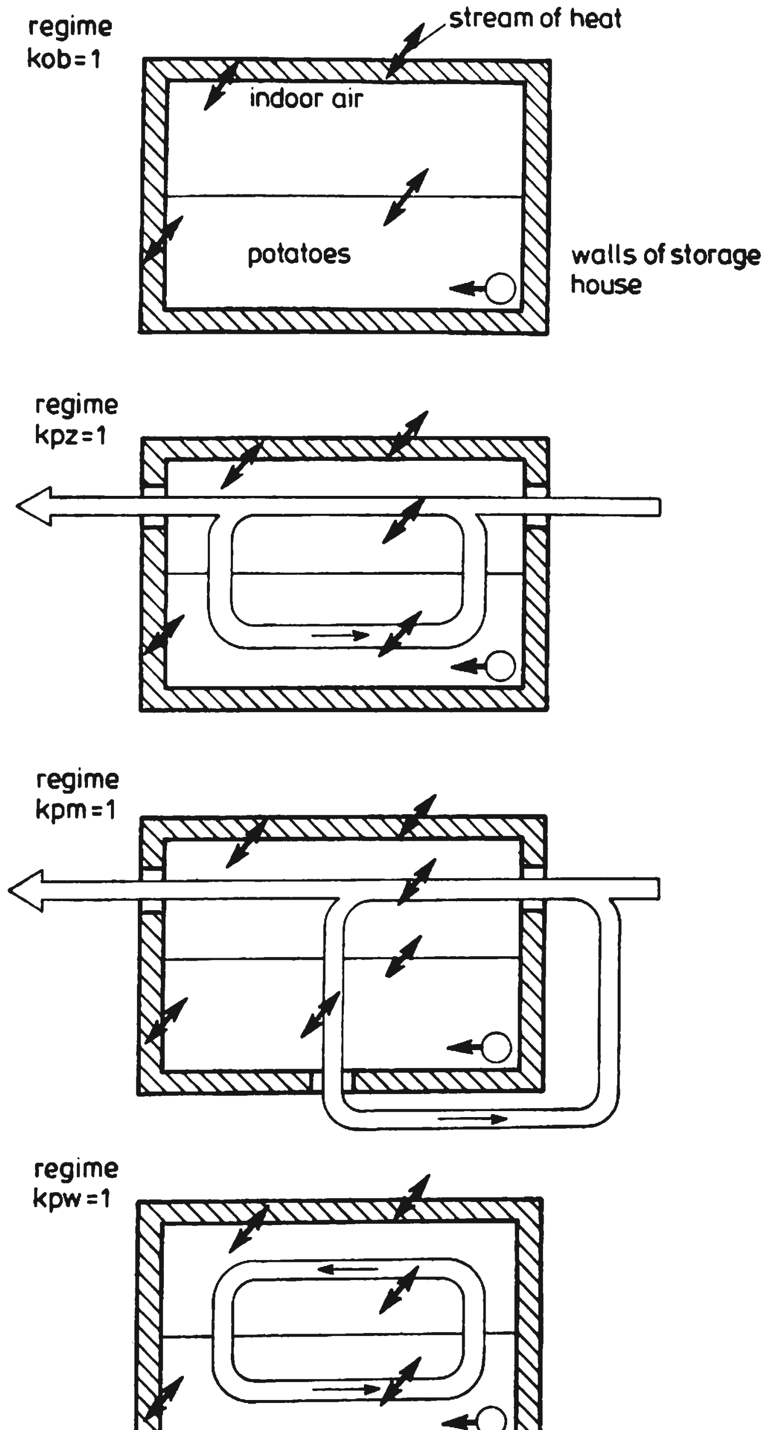

Fig. 2. Heat fluxes for various ventilation regimes

$$+ \ kpw \times (tpw\text{-}tzk)/Tkw2$$

$$d\ tsk/dc = (tpz\text{-}tsk)/Tsz1 \ + \ +(tpw\text{-}tsk)/Tsz1 \ + \ + \ (tzk\text{-}tsk)/Tsk1$$

where: tpw — temperature of indoor air, tzk — temperature of potatoes, tsk — temperature of store-house walls, tpz — temperature of outdoor air; kob, kpw, kpm, kpz — parameters characterizing the ventilation regime; Tws1, Twk1, Twz1, Twm1, Twk2, Tks1, Tkw1, Tkz1, Tkm1, Tkw2, Tsz1, Tsk1 — time-constants.

If the values of indoor and outdoor air streams are equal, the temperature of mixed air is described by

$$tpm = (tpz + tpw)/2.$$

LOGICAL MODELS OF CONTROL ALGORITHMS

Control algorithms ought to be devised taking into consideration the technological requirements, climatic conditions, and maximally low energy consumption. This can be achieved if the values of suitable parameters are available. The parameters of mixed air are particularly important here, and depending on them the ventilation control algorithms may be divided into three categories: 1) algorithms lacking information about the mixed air temperature, 2) algorithms utilizing this parameter measured after the start of ventilation, or so called "after algorithms", and 3) algorithms using information about the temperature of mixed air measured or calculated before ventilation begins, known as "before algorithms".

The first group of algorithms is sometimes used in very simple control systems, e.g. in storage facilities with no mixing of indoor and outdoor air. Such systems will not be considered here.

"After algorithms" are widely used in traditional storage. The drawback of these algorithms is that they allow temporary contact of potatoes with air of unsuitable temperature which leads to possible "stress" of the potatoes and losses thereof. There is no such risk in the case of "before algorithms". The structure of traditional control systems employing before algorithms is slightly more complicated than in systems with "after algorithms". For microcomputer control systems the degree of structure complexity is identical. Two simple algorithms are analysed here, namely STER1 and STER2, examples of "after" and "before algorithms", respectively. A very important advantage of algorithm STER2 over algorithm STER1 is that it may control both mechanical and mechanical-natural systems of ventilation, this offering further possibilities of energy saving. The logical models of algorithms STER1 and STER2 are as follows:

STER1

1. IF kpz = 0 AND kpm = 0 AND kpw = 0 THEN GO TO 3
2. IF tpn < tpn0 OR tpn > tpn9 THEN kob = 1
3. IF tkz > tkz9 THEN kpm = 1
4. IF tpw > tpw9 THEN GO TO 6
5. kob = 1
6. IF tpz > tpz0 AND tpz < tpz9 THEN kpz = 1
7. kob = 1

STER2

1. IF tpn < tpn0 OR tpn > tpn9 THEN kob = 1
2. IF tpw > tpw9 OR tzk > tzk9 THEN GO TO 4
3. kob = 1
4. IF tpz > tpz0 AND tpz < tpz9 THEN kpz = 1
5. IF tpm > tpm0 AND tpm < tpm9 THEN kpm = 1
6. kob = 1

where 0 or 9 at the end of parameter symbols denote the limit (minimum or maximum) values of these parameters.

MODEL OF RESPIRATION HEAT

The heat generated during respiration is of considerable importance for the ventilation system operation. The flux of respiration heat may be described as:

$$Q = kkx - kkx1 * tzk \quad \text{if } tzk \leqslant 3°C$$

or

$$Q = kkx1 * tzk - kkx \quad \text{if } tzk > 3°C,$$

where kkx and kkx1 are coefficients dependent on the sort and quality of potatoes. In a special case it may be assumed that kkx = 0.

ESTIMATION MODELS

Energy consumption during ventilation controlled by various algorithms is estimated by calculating the respective total times of ventilation operating according to regime kob = 1 or kpw = 1 or kpm = 1 or kpz = 1, and storing in memory the minimal and maximal temperatures during the simulated period. This makes it possible to monitor the quality of ventilation systems operation.

MODELS OF OUTDOOR WEATHER CONDITIONS

The time of simulation is determined in the program by the number of simulation events, with one day (24 hours) corresponding to 240 such events. Changes of outdoor air temperature (tpz) are modelled as functions increasing and decreasing linearly over intervals. Minimal and maximal temperatures are given for each successive simulation.

EXEMPLARY SIMULATION RESULTS

Previous empirical studies on storage facilities provided data on changes of temperatures of indoor air, potatoes and storage-house walls, for the outdoor air temperature changing within the ranges of -10-0°C and 0-10°C. The selected time-constants, parameters characterizing respiration heat, and other values simulate the operation of one of the studied storage facilities. A simulation model thus defined was then used in comparative simulation studies involving several different control algorithms.

The studies first concerned various simulation times. It was found that the basic differences in energy consumption for the various control algorithms may be ascertained following a simulation time coresponding to three days of storage-house operation. Exemplary results of such simulations for control algorithms STER1 and STER2 as well as for uncontrolled storage (STERO) are given below. Simulations were performed for the following conditions: two kinds of weather conditions in which the outdoor air temperature varies in the ranges

Table. Exemplary results of simulation

Outdoor air temperature	Initial value of parameter			Simulated algorithm	Time sum „ventilation in regime"		Time sum „temperature out of range"			Minimum value of temperature			Maximum value of temperature		
tpz	tpw	tzk	tsk	STER	kpz = 1	kpm = 1	tpw	tzk	tpn	tpw	tzk	tpn	tpw	tzk	tpn
−10÷0	5	5	5	0	0	0	719	720	—	5	5	—	7.3	7.4	—
				1	0	1	0	1	1	3.7	3.7	−1.3	5	5	−1.3
				2	0	1	109	110	0	4.5	4.6	2.0	5.1	5.2	2.0
	3.5	3.5	3.5	0	0	0	63	75	—	3.5	3.5	—	7.1	7.2	—
				1	2	44	42	45	38	3.5	3.5	4.6	6.2	6.2	6.3
				2	4	2	25	38	0	3.5	3.5	4.4	5.0	5.1	4.9
0÷10	5	5	5	0	0	0	719	720	—	5	5	—	16.5	16.7	—
				1	9	257	248	257	236	4.6	4.6	3.1	6.3	6.3	6.4
				2	18	8	191	229	0	4.5	4.5	2.3	5.2	5.2	4.9

-10-0°C and 0-10°C, respectively; three initial values (2, 3.5 and 5°C) of temperatures of indoor air (tpw), potatoes (tzk) and storage-house walls (tsk). The Table presents results of only those simulations for which the total sums of "temperature out of proper range" for indoor air, potato and wall temperature courses were non-zero. Comparing relevant total times for operation according to various regimes, especially regime kpm = 1 (mixed air ventilation) and regime kpz = 1 (outdoor air ventilation), we can see that ventilation control with algorithm STER1 leads to higher energy consumption than when ventilation is controlled with algorithm STER2.

CONCLUSIONS

1. A proper selection of ventilation-controlling algorithms offers considerable possibilities of saving energy in potato storage-houses. For example, energy consumption in the case of "before algorithms" is lower than for "after algorithms". This is a very important observation in the context of computer-controlled mechanical ventilation systems capable of mixing indoor and outdoor air, especially systems of mechanical-natural ventilation.
2. Computer simulation creates interesting prospects for comparative studies of energy consumption in potato storage facilities.

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PORÓWNAWCZE BADANIA SYMULACYJNE ZUŻYCIA ENERGII PODCZAS PRZECHOWYWANIA ZIEMNIAKÓW

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Streszczenie

Istotne możliwości oszczędności energii w nowoczesnym przechowalnictwie są w odpowiednim wyborze algorytmów do sterowania układami wentylacyjnymi i klimatyzacyjnymi. W procesach

wyboru można wykorzystywać porównawcze badania symulacyjne wzajemnych odddziaływań zachodzących pomiędzy układem przechowalniczym a układami sterującymi o różnych algorytmach sterowania. Praca zawiera krótki opis modeli zastosowanych do symulacji mikrokomputerowej. Program symulacyjny zawiera: dynamiczny model przechowalni, logiczne modele algorytmów sterujących, model ciepła generowanego przez ziemniaki w procesach oddychania, modele ocenowe oraz model zewnętrznych warunków pogodowych. Dynamiczny model przechowalni wykorzystuje równania bilansu energetycznego przedstawione w postaci układu równań różniczkowych pierwszego rzędu.

W logicznych modelach algorytmów sterujących uwzględniono wymagania technologiczne, uwarunkowania dotyczące układów wentylacyjnych, jak też warunek oszczędności energii. Modele ocenowe umożliwiają porównywanie energii zużywanej przy różnych algorytmach sterujących. Wyniki symulacji zilustrowano podając przykład.