MODELLING OF BEE WINTERING BUILDING PROFITABILITY

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S u m m a r y

A model for determining indoor wintering profitability was constructed using the program POWERSIM 2.51. The necessary heating or cooling power (N) to keep the target temperature in the wintering building is calculated using the equation $N = N_B + N_{V1} - N_S - N_G$, where N_B-metabolic power of bees, N_{V1}-power of recirculation fan, N_S-power lost through walls by heat transmission, N_G-power to warm-up the incoming air. N_B depends on the air temperature in the wintering building. The main input variables are air temperature and humidity outdoors, size of wintering building (number of colonies), capacity of heating and cooling systems, electricity costs, coefficient of heat transfer (CHT) of wintering building.

Output parameters are savings of consumed honey and physiological bee resources compared to reference group of bee colonies wintered outside. It was assumed that each 600 mg of saved honey means the additional saving of physiological potential of one new-born bee.

As a simulation, samples of the efficiency of indoor wintering in Manitoba (Canada) and Riga (Latvia) are compared.

Keywords: wintering building, modelling, physiological potential.

INTRODUCTION

Wintering indoors is one of the methods to improve the wintering results in regions with cold winters. Successful indoor wintering is described in different countries (Fingler and Small 1982, Murrell and McDonald 1986, Furgala and McCutchenon 1992). Practical tests in Latvia showed that under Latvian conditions, wintering buildings are not efficient (Argalis et al 1970). Theoretical calculations for an efficient bee wintering building in Latvia have been studied previously (Kristapsons et al 1996). A simulation model was created to investigate the economic efficiency of wintering buildings under different climatic circumstances. The model was made using software for dynamic modelling POWERSIM 2.51 (POWERSIM, Internet).

The aim was to compare the efficiency of wintering buildings constructed in Canada (Fingler and Small 1982) under Canadian (Manitoba, British Columbia) and Latvian (Riga) climatic circumstances, depending on the outside temperature, humidity and installed temperature control equipment.

METHODS

The calculations were based on the relationship between ambient temperature and heat power of bees (Eskov 1983, 1990; Ribockin and Zaharov 2001). The economics of honey and energy resource of bees were calculated. It was assumed that beehives in the wintering building were without additional insulation, had a sufficient amount of quality food and that the bees were healthy. The number of bees per hive was about 20,000. It was assumed that bees would not start intensive brood rearing in the spring in the wintering building.

The target of the control algorithm of the wintering building was to minimise the use of bees and honey as energy sources and replace them with electrical energy. The effect of indoor wintering was compared with an equally-sized control group wintered outdoors.

Calculations of the heat process were based on the equation of necessary warming (cooling) power N to keep the system in thermal balance (Kristapsons et al. 1996):

$$N = N_B + N_{V1} - N_S - N_G$$

where:
N_B – heat power of bees (W);
N_{V1} – capacity of recirculation fan (W);
N_S – heat losses through walls of the building (W);
N_G – power for heating up incoming air from outside (W).

The wintering simulation was done for a wintering building built according to described principles (Fingler and Small 1982). The building was equipped as follows:

— A continuous air recirculation system with a capacity of 18 m^3/h per hive (at 30 Pa). This system homogenised the air inside building.
— A cooling ventilation system controlling the inside temperature consisting of four suction fans with capacities of 0.9, 1.8, 3.6 and 11.7 m^3/h per hive (at 30 Pa). The fan with the smallest capacity constantly delivered the necessary amount of air for breathing of 0.9 m^3/h per hive. The oxygen was delivered and the excess carbon dioxide and water was removed. The suction fans also ensured additional cooling if the indoor temperature exceeded the set target temperature.

The following approximation was used to calculate the electrical capacity of all fans. The data was based on information on the electrical consumption of fans N_{nos} (W) (Kanalflakt 1999):

$$N_{nos} = aV + 15$$

where:
a – 0.0052 (Wd/m3);
V – capacity of fan at pressure difference 30 Pa (m^3/d).

— An electrical heater system controlling the indoor temperature with a maximum capacity of 10W per hive.

The electrical heater was used for heating and the cooling ventilation system was used for cooling. The control system sought to reach the nearest possible temperature to the target temperature if the capacity of the control means were not sufficient.

The simulation program was created on POWERSIM 2.51 software for dynamic simulations (POWERSIM, Internet).

The program had the following variables (parameters, where a value in brackets is indicated did not change in all of the described simulations:

— Start date (16 November) and end date (14 March) of indoor wintering (Kristapsons et al. 1996),
— Number of colonies wintered indoors (100 pcs.),
— Relative humidity in the wintering building (60%) (Fingler and Small 1982),

— Relative humidity outdoors (80%). It was possible to set the function of daily relative humidity during the winter, as so with outdoor temperature. However, the influence of this parameter was still not significant. Changes in relative humidity outdoors within 80±20% influence the economic parameters less than 1%.
— Coefficient of heat transmission C (W/°C) (Kristapsons et al. 1996). This parameter for a wintering building capacity of 100 hives in Manitoba was C=12.5 (W/°C) (Fingler and Small 1982),
— Maximal power of heating system (10 W/hive) could be changed by means of a coefficient,
— Maximal capacity of cooling ventilation system (18 m^3/h hive) could be changed by means of a coefficient,
— Target temperature in wintering building (6°C). The curve of heat capacity of bee colony had a minimum at outside temperature +8°C (Eskov 1990). If the temperature rose above the minimum point by 1°C, the heat power of bees increased about 5 times more compared to a decrease of 1°C. +6°C was used as a target temperature, which was displaced from the minimal value to a lower temperature to avoid warming up over +8°C even during oscillations in the transition process. In literature, the target temperatures in the wintering building are mentioned within an interval of 4-10°C (Furgala and McCutchenon 1992).
— It is possible to change the way of defining outside temperature. It is possible to use a sinusoidal rule of change and a sinusoidal rule with random oscillations (Stalidzans et al. 2001). In case of use of sinusoidal rule its maximum and minimum are the long-term average temperatures in July and January. It is possible to analyse the operation of wintering building in temperatures, which are given in the form of MS Excel sheets.
— The degree of thermoinsulation of the control group of bee colonies wintered outdoors (in all simulations, the control group of bee colonies is not additionally thermally insulated). It was assumed that the thermal processes in the insulated hive was equal to the one of the non-insulated hives in a higher outside air temperature. This temperature difference was assumed as the unit of measure of thermoinsulation. In the program, the effect of thermoinsulation of hives is expressed as a temperature difference (°C). That is, the outside temperature difference between non-insulated and insulated hives to keep their microclimates equal.

The most important output parameters of the program were:
— The parameter "Savings": saved honey (kg) and saved energy resource of wintering bees (%) compared to a control group of equal colonies wintered outdoors.

The honey was saved, replacing the heat energy of consumed honey by electrically driven control systems. The energy value of 1 g of honey was 11 400 (J).

It was more difficult to estimate the savings of energy resource of bees (Stalidzans et al. 2001). Savings are the difference between the resource of indoors (r_Z) and outdoors (r_K) wintered bee colonies in the day, when the indoor-wintered colonies leave the building in the spring. r_Z and r_K were calculated by the program. It was estimated that the energy resource of a single bee was 1.8±0.1 Wh, which was created after the consumption of A_m=0.6 g of honey (Stalidzans et al. 1999, 2000, 2001). Thus, every 0.6 g of saved honey corresponded to the energy resource of one newborn bee. The full (100%) resource R of a colony with n = 20,000 bees was R = nA_m = 20,000 x 0.6 = 12,000 (g) = = 12 (kg) of honey. The actual energy resource of a colony can be calculated as follows:

$$r_1 = \frac{R - m_1}{R} \quad 100(\%)$$

where:

m_i = honey spent by overwintered bees of the colony.

The economy of energy resources of bees could alternatively be expressed in the amount of wintered colonies of a control group with 20,000 bees to calculate the value of money for saved energy potential. Each R=12 kg of saved honey form an imaginary colony of 20,000 newborn bees with full energy potential. The value of saved colonies in the spring after wintering can be compared with the value of outdoor-wintered colonies from the control group. The amount of imaginary colonies with newborn bees has to be corrected to the one of equal number outdoor-wintered colonies (energy potential r_k).

Sample of calculation.
Given data:

Amount of saved honey in a wintering building of 100 hives M_i = 125 kg = = 125,000 g.
Energy resource of control colonies after wintering r_k = 38%.
Amount of consumed honey during life (energy resource) A_m = 0.6 g/bee

Calculation:

$$S_i = \frac{M_i}{A_m n r_k} = \frac{125000}{0{,}6 \quad 20000 \quad 0{,}38} \quad 27_{(colonies)}$$

where:

S_i – number of saved outdoors wintered colonies.

Now, it is possible to calculate the savings in terms of money if the costs of honey and wintered bee colony are known.

— Parameter "Costs": electric energy (kWh).

The running costs were the electrical energy spent by recirculation fan and heating and cooling control systems. Amortisation costs were not taken into account.

— Parameter "Profit": units of money.

This parameter can be calculated as difference between "Savings" and "Costs", when they are expressed in units of money and show the profit of use of wintering building. At this stage, to calculate the profitability of the wintering building, the amortisation costs could be considered. In this paper, units of money were not used as prices of energy, honey and colonies in spring are different from country to country.

RESULTS

The results of comparing the efficiency of wintering buildings (Fingler and Small 1982) under Riga (Latvia) and Manitoba (British Columbia, Canada) climatic conditions in table 1 show the importance of heating and cooling systems using a sinusoidal rule of annual temperature change.

Results indicate, that a wintering building with heating and cooling systems will be ~2x more efficient in Manitoba than in Riga.

A wintering building without a heating system in Manitoba had a decrease in economy by ~25%. Under Latvian conditions, a building without a heating system reduced the economy by ~10%.

The Manitoba wintering results were not influenced if a cooling ventilation system was not used (a constant suction fan and recirculating ventilation system was working constantly, in any case). Under Latvian winter conditions, the indoors wintered colonies would die because of high temperature if there were no system able to balance the indoor temperature with the outside temperature.

Table 1

Comparing the efficiency of a 100-hive wintering buildings in Manitoba (Canada) and Riga (Latvia) with different control systems. Long-term average temperatures (°C) in January and July in Manitoba and Riga were correspondingly (Jan: -15; Jul: +15) and (Jan: -5; Jul: +17). Coefficient of heat transmission C=12.5 (W/°C). Standard deviation is 4.

Combination of control systems	Calculated parameters	Manitoba (Canada)	Riga (Latvia)
With cooling With heating	Savings Costs Resource r_z/r_k	454 kg honey +39% en.res. 1817 kWh electroenergy 67% / 28%	220 kg honey +19% en.res. 907 kWh electroenergy 61% / 42%
With cooling No heating	Savings Costs Resource r_z/r_k	325 kg honey +27% en.res. 742 kWh 55% / 28%	203 kg honey +18% en.res. 772 kWh electroenergy 60% / 42%
No cooling With heating	Savings Costs Resource r_z/r_k	454 kg honey +38% en.res. 1818 kWh electroenergy 66% / 28%	48 kg honey +5% en.res. 857 kWh electroenergy 47% / 42%
No cooling No heating	Savings Costs Resource r_z/r_k	325 kg honey +27% en.res. 741 kWh electroenergy 55% / 28%	42 kg honey +3% en. res. 722 kWh electroenergy 45% / 42%

Table 2

Efficiency of the wintering building in cold and warm Latvian winter.

Type of winter	Calculated parameters	Riga (Latvia) C = 12.5	Riga (Latvia) C = 50
1991/92 warm winter	Savings Costs Resource r_z/r_k	114 kg honey +9% en.res. 888 kWh electroenergy 58% / 49%	114 kg honey +10% en.res. 1066 kWh electroenergy 59% / 49%
1995/96 cold winter	Savings Costs Resource r_z/r_k	326 kg honey +27% en.res. 1289 kWh electroenergy 63% / 36%	312 kg honey +26% en.res. 2395 kWh electroenergy 62% / 36%

In Manitoba, good results can be reached even if the wintering building is not equipped with any of the mentioned temperature control systems.

To study the demands for a rational bee wintering building in Latvia, further simulations were done for the a.m. wintering building. To get a better idea of the variety of Latvian climatic conditions, the warmest (1991/92) and coldest (1995/96) winters in the period of years 1991-2001 were used (Table 2). Data on the average outside temperature each day was imported from an MS Excel spreadsheet. During the indoor wintering period (16 November-14 March) the average outside temperatures in the Riga district in the winter of 1991/92 was +1.4°C, but in 1995/96 it was –7.1°C. Simulations were done at C=12.5 (W/°C), and C=50 (W/°C).

DISCUSSION

In comparing the efficiency of the wintering buildings (Fingler and Small 1982) in Manitoba (British Columbia, Canada) and Riga (Latvia) it was found that wintering buildings are more efficient in cold winters, when the heating system is functioning most of the time. The simulations were done using the average day and night temperature. Taking into account the momentary values of temperature, the cooling ventilation system would be more important for neutralising dangerously high temperature peaks, while profit would stay about at the same level and the extreme values would last only for a short time. For the heating system, the peaks of low temperature are not critical for bees and in the wintering building it will be better than outside.

CONCLUSIONS

The bee wintering building in Manitoba (British Columbia, Canada) (Fingler and Small 1982) for 100 bee hives, assuming a sinusoidal annual change of temperature in Manitoba (Jan. -15°C, Jul. +15°C) compared to an outside wintered control group, the saving was 454 kg honey and 39% of energy resources using 1817 kWh of electroenergy. Under Latvian conditions with average temperatures (Jan. -5°C, Jul. +17°C) the economy was 220 kg honey and 19% energy resources using 907 kWh of electroenergy.

Under Latvian conditions simulating a "cold" winter (average temp. –7.1°C) the economy is 326 kg honey and 27% energy resource spending 1289 kWh (C=12.5 W/°C) or 312 kg honey and 26% of energy resource spending 2395 kWh (C=50 W/°C). In case of a "warm" winter (average temp. +1.4°C), the economy is 114 kg honey and 9% energy resource spending 888 kWh of energy (C=12.5 W/°C) or 114 kg honey and 10% energy resources using 1066 kWh of electroenergy (C=50 W/°C). Amortisation costs of the building and equipment were not taken into account.

A low coefficient of thermal transfer of wintering building is important in cold winters, when a heating system is used. The heating system is not critical for the bees' survival, but it can significantly increase the rentability of the building, especially in cold winters. Thermoinsulation has no significant impact when the wintering building is cooled by a ventilation system.

In wintering buildings, especially in Latvia with relatively high temperatures, the cooling ventilation system becomes critical. The capacity of the cooling ventilation system has to be calculated taking into account the coefficient of heat transmission of the building and estimated maximal momentan of outside temperature during bee wintering.

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MODELOWANIE DOCHODOWOŚCI BUDYNKÓW PRZEZNACZONYCH DO ZIMOWANIA PSZCZÓŁ

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Streszczenie

Model oceny dochodowości budynków przeznaczonych do zimowania przygotowano przy użyciu programu POWERSIM 2.51. Moc grzewczą lub chłodzącą (N) wymaganą do utrzymania zamierzonej temperatury w pomieszczeniach do zimowania obliczono przy pomocy równania $N = N_B + N_{V1} - N_S - N_G$, gdzie: N_B-siła metaboliczna pszczół, N_{V1}-moc wentylatora recyrkulacyjnego, N_S-moc utracona w wyniku przenikania ciepła przez ściany, N_G-moc potrzebna do ogrzania napływającego powietrza. N_B zależy od temperatury powietrza w budynku przeznaczonym do zimowania. Głównymi zmiennymi wejściowymi są temperatura i wilgotność powietrza na zewnątrz, wielkość pomieszczenia przeznaczonego do zimowania (liczba rodzin), wydajność systemów grzewczych i chłodzących, koszty energii elektrycznej, współczynnik przenikania ciepła (WPC) pomieszczenia do zimowania.

Parametrami wyjściowymi są oszczędności w kosztach oraz zasobach fizjologicznych pszczół w porównaniu do rodzin pszczół zimujących na zewnątrz tworzących grupę odniesienia. Zakłada się, że każde 600 mg zaoszczędzonego miodu oznacza dodatkowe oszczędności w potencjale fizjologicznym jednej nowonarodzonej pszczoły.

Jako próby symulacyjne porównano w Manitobie (Kanada) i Rydze (Łotwa) skuteczność zimowania w budynkach różnej konstrukcji.

Słowa kluczowe: budynek do zimowania, modelowanie, potencjał fizjologiczny.