

Modernisation of calculations methods and tools for energy, heat and moisture balance assessment of agriculture buildings

1. Background – Importance of indoor thermal climate in agriculture buildings

Good indoor climate in agricultural buildings is essential to ensure low energy use in horticulture production, as well as to maintain good animal welfare in livestock buildings. A poor indoor climate in, for example, greenhouses may lead to suboptimal conditions for plants. Similarly, in livestock buildings, it can result in a reduction in production (e.g., milk, meat, egg) or an increase in feed consumption when indoor temperatures are too low. The indoor climate is also a key factor influencing animal welfare and behaviour.

Consequently, maintaining a good indoor thermal climate in agricultural buildings (including horticulture and livestock buildings) is a crucial aspect of low-energy, sustainable agricultural practices. In the future, this topic will gain significance due to climate change, with projected higher humidity and more frequent heat waves. Furthermore, the anticipated increase in energy costs resulting from carbon taxes or restrictions on electricity use due to population growth means that the energy question will gain importance in the future.

1.1 Teaching building science at SLU within the ‘lantmästarprogram’

Teaching and learning the science and technology required to maintain a good indoor climate in agricultural buildings with low energy use is an essential element of sustainable agriculture practices. This topic has been taught at SLU during the last decades, relying on well-established methods in building physics, which involve heat transfer through building envelopes, see e.g. [1, 2].

However, there was a clear need for a modernization of calculation methods, as they were primarily based on manual calculations. Manual calculations were challenging for students and prone to errors due to the large amount of input data required, especially with complex building geometries. An example of such manual calculation for a milk producing cow stable is shown in Figure 1. With these calculations, students' efforts were primarily spent trying to determine the size of the building envelope, and they often missed the main point of the

environment where lighting, ventilation, and internal heat loads (from animals) vary throughout the day.

1.2 Aim of this best practice project

The aim of this Best Practice project was to develop a digital calculation tool using the steady-state calculation method and test it in two courses within the programs ‘Lantmästare’ and ‘Husdjuragronom’. The second objective was to implement a dynamic calculation method at a later stage, which could be taught in a follow-up course called ‘Energisystem och energihushållning för landsbygdsföretag’ (TN0341, 7,5 hp).

The first part of this Best Practice project was fully developed and tested with the students enrolled in the courses ‘Technology for Animal Husbandry’ (TN0340, 15 hp) and ‘Machinery and building functions in animal houses’ (TN0357, 7,5 hp). In both course, the digital tool was used to perform exercises in class as well as in a newly implemented digital exam in Inspira.

The second part of this Best Practice project was prepared but could not be tested as the course ‘Energisystem och energihushållning för landsbygdsföretag’ was cancelled due to low registrations. However, we still plan to use this development in future courses so the exercise is nevertheless presented further down.

2. Method development

2.1 Excel-based steady-state energy calculation

The first tool developed is an Excel-based tool, where students can enter information about:

- 1) building geometry,
- 2) thermal conductance (U-values) of different building parts (wall, roof, floor, etc.),
- 3) type and quantity of animals and/or heat lamps used in the stable,
- 4) extra ventilation.

Each of these input parameters is entered in a separate sheet, as shown in Figures 2-5. The sheets were programmed to facilitate the input. In the geometry section, students are given the choice of selecting either a rectangular or L-shaped plan, which is sufficient to represent most animal stables. Surface areas are calculated automatically based on information about length and width, which greatly facilitates learning for the students.

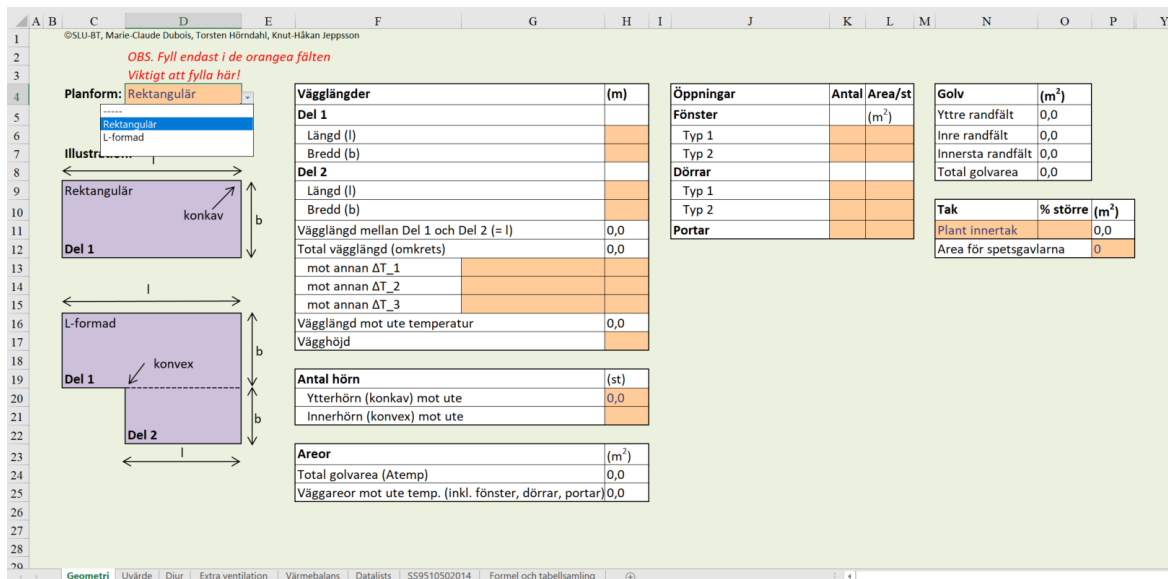


Figure 2: Geometry input showing the choice of plan (rectangular or L-shaped).

The second sheet is for thermal conductance of building parts. In this sheet, the students enter the U-value (W/m²°C) of each part, while the areas are automatically retrieved from the geometry sheet. The calculation of the heat loss coefficient (U x A in W/°C) is computed automatically at the bottom. Drop-down menus were programmed for windows to facilitate input, see Figure 3. Note also that the equation used in the calculation [$P_{trans} = \sum U_i A_i (T_{iv} - T_{uv})$] and taught during the lecture is presented at the bottom to make sure that the students make the connection between theory and application.

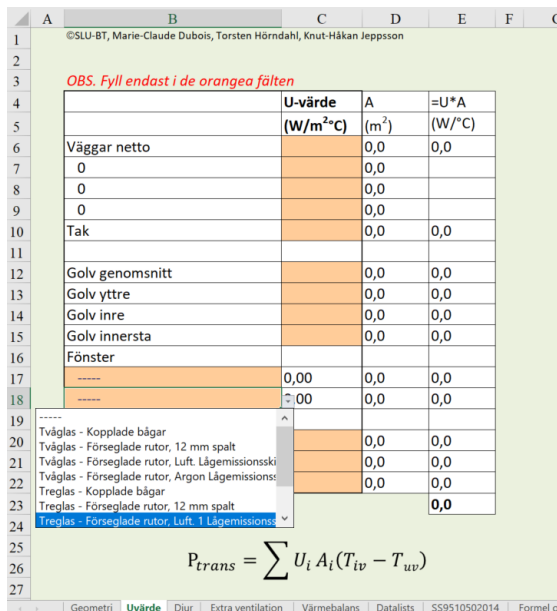


Figure 3: Input sheet for thermal conductance (U-value) of buildings parts.

In the next sheet, the input concerns type and quantity of animals, see Figure 4. Once again, drop-down menus were programmed for the animal selection, leading to easier input for the students. The data regarding minimum (qmin) and maximum (qmax) ventilation (m³/h) is retrieved automatically from the sheet "Datalists", which is based on Standard SS-9510502014 [3], also made directly accessible in the Excel tool as shown in Figure 4.

Klimatreglerat stall				CO ₂	A	B	C	D	E	Pfri	qmax
tiv	qmin										
°C	m ³ /h	m ³ /h	m ³ /h	m ³ /h	m ³ /h	m ³ /h	m ³ /h	W	m ³ /h		
10	10 320	17 400	15 600	15 600	15 000	14 400	102 000	49 200			
120											
0											

Figure 4: Input sheet for type and quantity of animals showing an example with 120 cows (9000 kg milk/year).

The fourth sheet concerns extra ventilation needs, which may be part of certain problems. For example, the calculation may concern an adjacent room for employees with minimum ventilation needs of 0,35 L/s m² floor area, which is required by the Swedish building regulations [4]. In this sheet, different input units are enabled through another drop-down menu, see example in Figure 5. Other quantities (air volume, ventilation need, and heat loss coefficient) are calculated automatically based on information retrieved from the geometry sheet. Once again, the equation taught in class [$P_{vent} = c_p nV(T_{iv} - T_{uv})$] is shown on the right side to make sure that the students make the connection between theory and application.

Luftens spec. värmekapacitet (c _p)	Indata	Uppvärmd volym (V)	nV	c _p nV
(Wh/m ³ °C)		(m ³)	(m ³ /h)	(W/°C)
0,33		0		

$$P_{vent} = c_p nV(T_{iv} - T_{uv})$$

Figure 5: Input sheet for additional ventilation needs not given in the animal (djur) sheet.

The last sheet provides the output (result) calculation for the thermal balance. This sheet retrieves information from all previous sheets including geometry, animals, extra ventilation, etc. The only input required is the climate zone (A-E) and required indoor temperature (T_{iv}, cell D8, Figure 6), as well as temperature conditions in adjacent spaces (cells J41-44, Figure 6). There is also a possibility to add extra internal heat loads (“extra internvärmelaster”) in cells C34 and D34. Note that the sheet

has been programmed to provide an interpretation of the final result with words such as “värmebehov” indicating a heating need with negative result or “övervärme eller kylbehov” (overheating) when a positive result is obtained.

Klimatreglerat stall		Min qmin (vinter)	Max ventilation qmax (sommar)					
tiv	CO2	A	B	C	D	E	Pfri	Max ventilation qmax (sommar)
°C	m³/h	m³/h	m³/h	m³/h	m³/h	m³/h	W	m³/h
10	17400	0	0	0	0	0	102000	49200
TOTAL DIJUR		0	17400	0	0	0	102000	49200
LAMPOR		0						
EXTRA INTERNVÄRMELASTER		0					0	
EXTRA VENTILATION		0						
TOTAL		0	17400	0	0	0	102000	49200

	t iv (°C)	Δt (°C)	W
Ventilation	10	20	-114840
Värmeledning, huvudbyggnad	10	20	0
0		10	0
0		10	0
0		10	0
			-12840

värmebehov

Figure 6: Result sheet showing the thermal balance calculation.

This Excel tool was introduced to the students and then tested through a series of exercises performed in class so the students could understand how one goes from problem formulation to input in the Excel sheets. The exercises used were the same as previously used with the manual calculation method, see Appendix A.

2.2 Dynamic energy simulation

The second part of this Best Practice project focused on the development of an exercise based on a dynamic calculation method. For this part, the program ESBO Light [5] was selected as it is a free, simplified version of the well-known Swedish program IDA-ICE [6]. This program has been scientifically validated and it is well established within the engineering consultancy practice in Scandinavia.

For this exercise, we prepared a model in ESBO Light faithful to the model described in the exercise below (in terms of geometry and material properties). The model as built in ESBO Light is shown in Figure 8.

Exercise:

Personalrumtill Grisproduktion i zon A enligt bifogad ritning. Även om det är innerväggar i lokalen räknar vi allt som en lokal. Takhöjden är 2,4 m. Temperatur inne 22°C, Temperatur i omgivande rum 22°C.

- Ytterväggar U-värde 0,25 W/m²°C,
- Tak U-värde 0,15 W/m²°C,
- Golvet har följande U-värden; Uyttre= 0,28 W/m²°C, Uinre = 0,18 W/m²°C,
- 2 st 3-glas fönster, (1 m²/st),
- 1 st 3-glas fönster (0,5 m²/st),
- Samtliga fönster är av typen ”kopplade bågar”.

- 1 Dörr (mot ute), 2 m²/st, U-värde 0,9 W/m²°C.
 Ventilation: 0,35 l luft/s, m² (krav enligt BFS 2011:16). Beräkna vilket värmebehov som finns på vintern. (Svar: 0,87 kW)

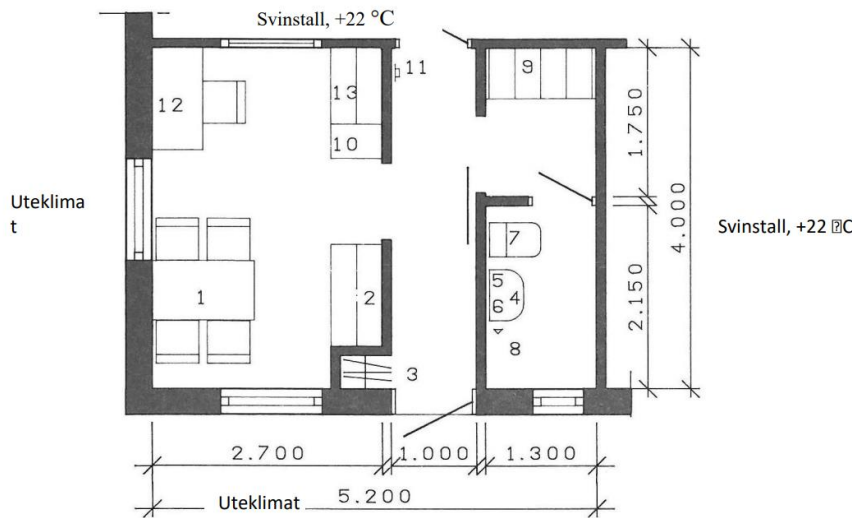


Figure 7: Plan of the employees' rum adjacent to a pig stable.

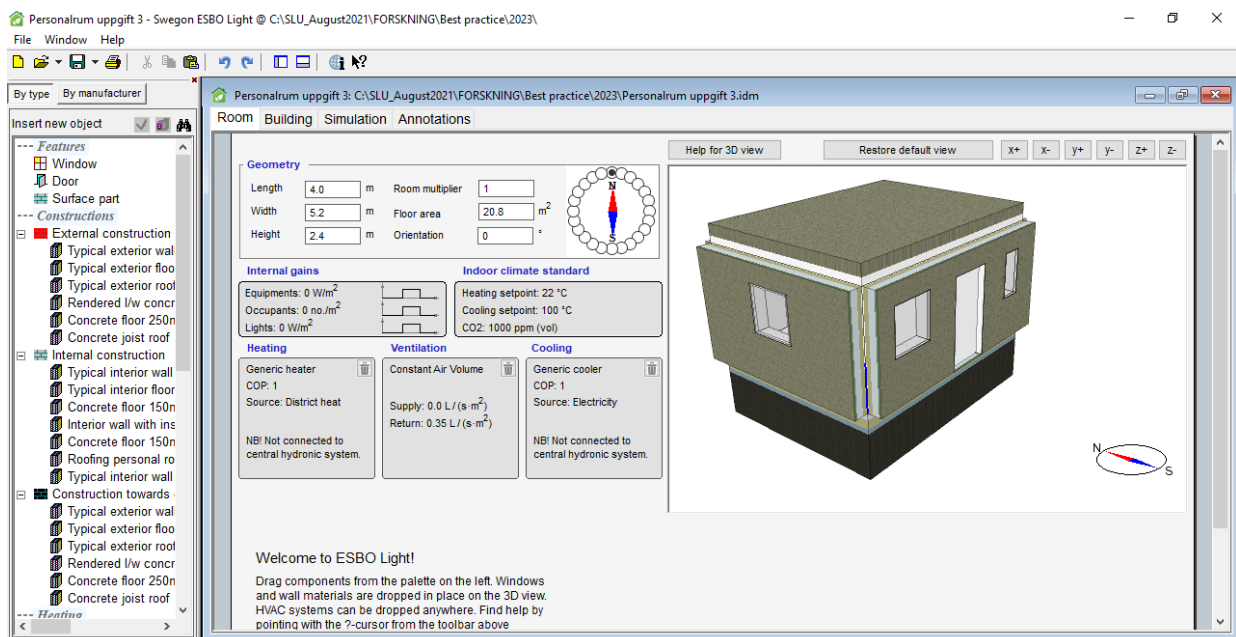


Figure 8 Model of employees' room in ESBO Light.

The exercise with the dynamic energy simulations is described below.

Exercise, dynamic energy simulations

Go to the Swegon website: <https://www.swegon.com/support/software/swegon-esbo/>

Download the program ESBO Light on your computer. Open Canvas and save the file called "Personalrum uppgift 3" on your computer. Open ESBO Light and open the model "Personal rum uppgift 3". You will see a 3D model of the personal room described in Exercise 3.

Explore this model without changing any setting. Then click on the menu “simulation” and perform a “Heating design” calculation. Open the report and compare your results with the steady-state calculations previously performed with Excel in this course.

Under the same menu (“simulation”), perform an “Energy (whole year)” simulation. Click on “report” and save it on your computer by right-clicking and selecting “print”. Print the report as a pdf file. Open this report and examine the distribution of energy use for each month.

The next step in this exercise consists of proposing three (3) variations to the personnel room that would affect its energy use. It could be, for example, changing the orientation, the window sizes, the U-values, the window type, etc. For each variation, perform an annual energy simulation and save the results as a separate pdf file.

Prepare a 2-page report comparing your base case results to the three proposed variations. Your report should contain at least one summary table or one graph showing all your results (annual energy use). Provide a discussion and conclusion about your results (What are the main lessons learned? What other variations could you study if you had more time?). You should also provide an introduction presenting the problem and a method section explaining your inputs.

3 Results

3.1 Static energy calculations

Some of the objectives of the courses ‘Technology for Animal Husbandry’ (TN0340, 15 hp) and ‘Machinery and building functions in animal houses’ (TN0357, 7,5 hp) are described below:

-Describe the most common building materials, construction principles and technical aids within Swedish animal housing,

-Perform a design of ventilation needs, and combine this with a calculation of heat balance.

The last objective demands an understanding of underlying building physics’ principles and thermal balance, which is a complicated calculation based on building geometry, materials, temperature conditions, ventilation needs, and specific heat production for each animal, etc.

The Excel-based tool used in class to support exercises has proven invaluable as a learning aid. Students are now less focused on solving complicated geometrical calculations and more on understanding the basic principles of heat balance. We have received many positive feedback about the tool from students both during and after the course. The access to the Excel tool during the Inspera exam was also seen as a positive aspect, see exam example in Appendix B.

Using Excel has also allowed the development of the students' digital skills. Their understanding of the Windows operating system was limited at the beginning of this course. For instance, they were unaware that one could download a file to the C drive's download folder, work on this file, save it under a different name, and upload the file from the download folder onto a website (in the Inspera exam). The most basic computer operations

were not familiar to students enrolled in this program. A first step into the digital world (before starting to program with AI) is being able to perform these simple digital operations, and the use of the developed tool in Excel is certainly one step in this direction.

In the longer run, we hope to be able to implement the dynamic energy simulation tool ESBO-Light as the first step into the simulation world. This will support learning in the course 'Energisystem och energihushållning för landsbygdsföretag'.

4 Conclusion and future work

In conclusion, an Excel-based, steady-state calculation tool for heat balance was developed and tested as part of this Best Practice project. Exercises were performed in class using this tool, and the tool was used in a digital exam on Inspira. This tool has proven invaluable as a learning aid in two courses at SLU in the programs 'Lantmästare' and 'Husdjuragronom'.

An exercise based on the dynamic energy simulation program ESBO-Light was developed. For this, a model was built and validated with the steady-state calculations. The model returned the same results as the steady-state calculations. The exercise was prepared but could not be tested due to low registrations for the course. Nevertheless, the exercise is valuable and ready for use in the next course opportunity.

As part of this work, we also explored the potential for developing a web-based version of the Excel calculation tool. A mock-up version of this web-based tool was programmed by the company Unicus (a company hiring individuals with autism) using the programming language React. We have also been in contact with SLU Holding for discussions on financing further development of this tool, which has potential for commercialization. This discussion is still ongoing at the time of writing this report.

Other envisioned developments concern the need for digital tools regarding:

- Calculation of natural ventilation in animal buildings,
- Calculation of moisture risks,
- Daylighting and lighting calculations.

Note that part of the moisture risk assessment have already been developed as part of a course called "Byggnadskonstruktion A" (TN0254, 15 hp) (not presented here).

We have also started discussions with the company Equa to initiate the development of a customizable dynamic energy simulation tool specific to animal stables. Equa is interested to pursue this development and we plan to apply for funding for this project in February, in the Vinnova call <https://www.vinnova.se/en/calls-for-proposals/smart-built-environment/smart-built-environment-digital-2023-03762/>.

References

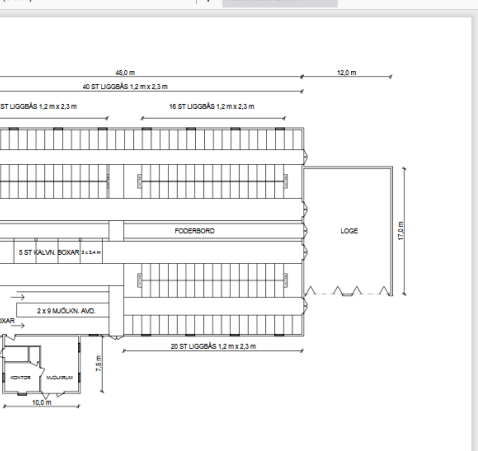
- [1] Hagentoft C.-E., Sandin K. (2017). Byggnadsfysik: så fungerar hus. Första upplaga. Studentlitteratur, Lund. 280 s. ISBN 9789144114484.
- [2] Sandin K. (2010). Praktisk byggnadsfysik. Första upplaga. Studentlitteratur, Lund. 205 s.
- [3] Swedish standard institut. (2014). Lantbruksbyggnader – Ventilations-och värmebehov i djurstallar. [Elektronisk]. Stockholm: SIS Förlag AB. (SS 95 10 50: 2014)
- [4] Boverket (2020). Boverkets byggregler BBR, BFS 2011:6 med ändringar till och med BFS 2020:4. Boverket, Karlskrona.
- [5] Swegon (2023). ESBO Light, accessed 2023-12-07 via <https://www.swegon.com/support/software/swegon-esbo/> [Internet resource].
- [6] Equa (2023). IDA-ICE, retrieved 2023-12-07 via <https://equa.se/en/> [Internet resource].

Appendix A Exercises used to teach the steady-state energy calculations.

Räkneuppgifter värmebalans

- 1) En verkstad som är 12,0 m bred och 8,0 m lång med vägghöjd 5,0 m har följande konstruktion:
- Väggar har U-värde $0,86 \text{ W/m}^2\text{C}$,
 - Taket har U-värde $0,14 \text{ W/m}^2\text{C}$ (plant innertak),
 - Golvets U-värden är följande; Uyttre = $0,35 \text{ W/m}^2\text{C}$, Uinre = $0,25 \text{ W/m}^2\text{C}$.
- På byggnaden finns det:
- 5 st, 2-glasfönster ($1 \text{ m}^2/\text{st}$, kopplade bågar),
 - 1 st port (15 m^2 , U-värde $1,5 \text{ W/m}^2\text{C}$).
- Byggnaden är inte helt tät utan ventilerar ca $10 \text{ m}^3/\text{tim}$. Innetemperatur $+15^\circ\text{C}$. Verkstaden är belägen i Zon D. Beräkna värmebehov på vintern. (Svar: $8,2 \text{ kW}$)
- 2) En lagerbyggnad som är 11,0 m bred och 25,0 m lång med vägghöjd 4,0 m har följande konstruktion:
- Väggar har U-värde $0,3 \text{ W/m}^2\text{C}$,
 - Tak, (parallelltak) har U-värde $0,13 \text{ W/m}^2\text{C}$ (takytan är därför således 10 % större än golvytan). Gavlarna blir något större men detta tar vi ingen hänsyn till.
 - Golvet har följande U-värden; Uyttre = $0,4 \text{ W/m}^2\text{C}$, Uinre = $0,23 \text{ W/m}^2\text{C}$.
- På byggnaden finns det:
- 1 port på 16 m^2 med U-värde $1,3 \text{ W/m}^2\text{C}$, inga fönster finns.
 - Lagret innehåller 400 ton potatis som avger 9 W/ton . Vintertid läcker byggnaden $40 \text{ m}^3/\text{tim}$.
- Byggnaden är belägen i Zon B. Innetemperatur är $+5^\circ\text{C}$. Beräkna vilket värmebehov som finns på vintern. (Svar: 1 kW)
- 3) Personalrum till Grisproduktion i zon A enligt bifogad ritning. Även om det är innerväggar i lokalen räknar vi allt som en lokal. Takhöjden är 2,4 m. Temperatur inne 22°C , Temperatur i omgivande rum 22°C .
- Ytterväggar U-värde $0,25 \text{ W/m}^2\text{C}$,
 - Tak U-värde = $0,15 \text{ W/m}^2\text{C}$.
 - Golvet har följande U-värden; Uyttre = $0,28 \text{ W/m}^2\text{C}$, Uinre = $0,18 \text{ W/m}^2\text{C}$.
- 2 st 3-glas fönster, ($1 \text{ m}^2/\text{st}$),
 - 1 st 3-glas fönster ($0,5 \text{ m}^2/\text{st}$), Samtliga fönster är av typen "kopplade bågar".
 - 1 Dörr (mot ute), $2 \text{ m}^2/\text{st}$, U-värde $0,9 \text{ W/m}^2\text{C}$.
- Ventilation: $0,35 \text{ l luft/s, m}^2$ (krav enligt BFS 2011:16). Beräkna vilket värmebehov som finns på vintern. (Svar: $0,87 \text{ kW}$)
- 4) Gårdsbutik i zon D med vägghöjd 2,8 m enligt bifogad ritning. Även om det är innerväggar i lokalen räknar vi allt som en lokal. Temperatur inne 20°C . Temperatur i omgivande rum och lager är $+10^\circ\text{C}$.
- Fönster 3 st 3-glas fönster (kopplade bågar), $1,1 \text{ m}^2/\text{st}$,
 - 2 Dörrar ($2 \text{ m}^2/\text{st}$), $0,9 \text{ W/m}^2\text{C}$.
- U-värde är;
- Samtliga väggar $0,22 \text{ W/m}^2\text{C}$,
 - Tak (plant innertak) $0,17 \text{ W/m}^2\text{C}$,
 - Golvet har följande U-värden: Uyttre = $0,4 \text{ W/m}^2\text{C}$, Uinre = $0,23 \text{ W/m}^2\text{C}$.
- Ventilationsflöde: $96 \text{ m}^3/\text{tim}$., ($0,35 \text{ l/s, m}^2$ är krav enligt BFS 2011:16). Beräkna vilket värmebehov som finns på vintern. (Svar: $3,7 \text{ kW}$)

Appendix B Example of thermal balance calculation with Excel tool in Inspera.



Ventilationsbehov och värmebalans

Ett stall för mjölkkor är beläget zon A ser ut som ritningen visar. I stallet finns en besättning av 150 mjölkkor (10 500 kg per år) med det antal platser som ritningen visar. I kalvman finns 10 kalvar (90 kg). Räkna med att det finns en spädkalv (60 kg) i varje box. Kalvningsboxarna har inga djur.

Beräkna:

A)

- 1) ventilationsbehovet på vinter,
- 2) ventilationsbehovet på sommar,
- 3) den fria värmeavgivningen från djuren.

B) Räkna behovet av tillskottsvarme för stallet med följande förutsättningar. Vägghöjd är 3,0 m. I beräkningen behöver du inte ta hänsyn till den triangulära delen på gavlarna. På vintern är temperaturen i mjölkkrummet +14°C. "Logen" håller +5°C. Samtliga väggars U-värde är 0,38 W/m²°C. Väggen mot mjölkkrummet tar 30 m² och du kan räkna med 0,38 W/m²°C som ett medelvärde för denna vägg (inkl. dörr). Takets U-värde är 0,40 W/m²°C och takytan i kostallet är 4% större än golvytan (parallelltak). Genomsnittligt U-värde för golvet är 0,27 W/m²°C. Det finns bara 1 enkeldörr som är 2 m², 8 dubbeldörrar som är 5 m²/st och 1 port som är 8 m². Alla har U-värdet 1,1 W/m²°C. Fönstren (18 st) är 2-glasfönster kopplade bågar och är 1,1 m²/st.

Du kan använda Excel arket som finns här: [Värmebalans_TN357 och 340_HT2023](#) och lämna in den i uppgiften "Värmebalans inlämning av Excel".

OBS. Du kan ändra bildstorlek med hjälp av de tre prickar. GLÖM INTE ATT SKRIVA DINA SVAR NEDAN FÖR BÅDA A) OCH B).

Skriv in ditt svar här [Hjälp](#)

Teckenf... | **B** | **I** | U | **x** | **x²** | \int | $\frac{\square}{\square}$ | \leftarrow | \rightarrow | \curvearrowright | \equiv | Ω | Σ | \otimes