ENERGY EFFICIENT HOUSES IN DENMARK AND MOISTURE IN HIGHLY INSULATED CONSTRUCTIONS – RULES, PRACTISE AND EDUCATION

ANKER NIELSEN

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

RULES FOR ENERGY EFFICENT HOUSES

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Danish Building Regulation

1961, 1967, 1972, 1977, 1982, 1985, 1998, 2006

U-values for each construction part

- Outer wall
- Basement wall
- Floor
- Roof
- Windows

In 2010 maximum energy demand was

- reduced by 25% compared with 2006
- New rules for the future

Tightened energy requirements for new buildings from 2010

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

- In 2015 requirements will be tightened by a total of 50% compared with 2006
  - Energy frames becomes 57% lower

- Building class 2020 was introduced in BR10 by July 2010 with an additional tightening of approx. 75% compared to 2006
  - Energy frames for new buildings tightened to 42%

Rules for U-values

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Construction	**U-value W/m²K**
External wall and basement walls in contact with the soil	0.3
Partition walls and suspended upper floors adjoining rooms/spaces that are unheated or partly heated	0.4
Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space	0.2
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.2
Windows, including glass walls, roof lights and skylight domes, external doors and hatches to the outside or to rooms/spaces that are unheated or partly heated	1.8

Avoid cold bridges

Maximal Linear heat losses	**W/mK**
Between external wall and ground slabs	0.4
Between external wall and windows/doors	0.05
Between roof and windows/doors	0.2

Dimensioning[1] heat loss through the opaque thermal envelope (no doors and windows)

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

	2010	2015	2020
1 storey	Q <= 5 W/m²	Q <= 4 W/m²	Q <= 3.7 W/m²
2 storeys	Q <= 6 W/m²	Q <= 5 W/m²	Q <= 4.7 W/m²
2+ storeys	Q <= 7 W/m²	Q <= 6 W/m²	Q <= 5.7 W/m²

1) $\Delta T = 32$ °C

U-values Case 2020 single 1 storey

Heat loss 3,7 W/m2 and 32 C temperature difference

Average U-values

$U_{average}$ = 3.7/32= 0.116 W/m^{2}K

Gives around 300 mm insulation

Practice outer wall with 190 mm insulation

U_{wall} = 0.16 W/m^{2}K

Extra insulation for roofs and floor to 450-500 mm

U_{roof} = 0.07-0.08 W/m^{2}K

NB cold bridges also has to be included

Energy frame – *total heating, ventilation, hot water, electricity*

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Residential

2010

52,5 + 1650/A kWh/m² year

2015

30 + 1000/A kWh/m² year

2020

20 kWh/m² year

Non-residential

2010

71,3 + 1650/A kWh/m² year

2015

41 + 1000/A kWh/m² year

2020

25 kWh/m² year

Typical values for buildings

Primary energy use kWh/m^{2}year	**2006**	**2010**	**2015**	**2020**
Residential, 150 m^2 heated gross floor area	84.7	63.0	36.7	20.0
Non-residential, 1000 m^2 of heated gross floor area	97.2	73.0	42.0	25.0

Air tightness

Rules for year	Maximal leakage at 50 Pa	Maximal opening With area = 160m²
2010	1.5 l/s pr. m²	21 x 21 cm
2015	1.0 l/s pr. m²	17 x 17 cm
2020	0.5 l/s pr. m²	12 x 12 cm

2010: The Municipality must require a pressure test in no less than 5% of all new buildings

Fulfilment of 2015 or 2020 regulations requires always a pressure test.

Windows – Energy balance (heating season)

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

$$E_{ref} = I \cdot g_w - DD \cdot U_w = 196{,}4 \cdot g_w - 90.36 \cdot U_w$$

g_w = total solar transmittance for window
U_w = total U-value for window

E_{ref} = energy gainfactor in kWh/m^2 year

	2010	2015	2020
Facade windows	-33	-17	+ 0
Window energy labels	A or B or C	A or B	A

Ventilation in dwellings

- In a dwelling the rate of outdoor air must not be less than 0.3 l/s pr. m² heated floor area (½ air-change per. hour)
- Kitchens must be equipped with a cooker hood with controllable ventilation and exhaust to the ambient
- Single family houses can be ventilated by either mechanical or natural ventilation
- In case of balanced mechanical ventilation, the system must be equipped with an efficient heat recovery unit

Ventilation systems

Heat recovery:	Min.	70 %
Heat pumps: COP (efficiency)	Min.	3.6

SEL specific electricity use	Max. SEL J/m³
Mechanical exhaust ventilation	800
Mech. vent. in single dwelling	1 000
CAV (Constant air volume)	1 800
VAV (Variable air volume)	2 100

CALCULATE ENERGY FRAME

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Be10

Check that the building is inside the energy frame

Description in SBi direction 213 (Danish)

Follows CEN standards

Input:

- Areas
- U-values
- Windows
- Ventilation
- Hot water
- Persons
- Heat recovery
- Solar panels
- etc.

Eksempel_v6b_Parcelhus - Be10

Filer Rediger Vis Hjælp

SBi anvisning 213: Bygningers energibehov, Be10

- Eksempel: Parcelhus 180 m2 med T-knast
  - Klimaskærm
    - Ydervægge, tage og gulve
      - Skema 1
    - Fundamenter mv.
      - Skema 1
    - Vinduer og yderdøre
      - Skema 1
    - Skygger
      - Skema 1
    - Uopvarmede rum
  - Ventilation
    - Skema 1
  - Internt varmetilskud
    - Skema 1
  - Belysning
    - Skema 1
  - Andet elforbrug
    - Parkeringskældre mv.
  - Mekanisk køling
  - Varmefordelingsanlæg
    - Skema 1
    - Pumper
      - Pumpe-skema 1
  - Varmt brugsvand
    - VBV Beholder
      - Skema 1
      - PumpCirc
        - Skema 1
    - Vandvarmere
  - Forsyning
    - Kedler
      - Ny kedel
    - Fjernvarmeveksler
    - Anden rumopvarmning
    - Solvarmeanlæg
    - Varmepumper
      - Udeluftvarmepumpe
    - Solceller
      - Nyt solcelle anlæg
    - Vindmøller
  - Resultater
    - Nøgletal
    - Varmebehov

Bygning

Navn: Eksempel: Parcelhus 180 m2 med T-knast

Fritligge — Fritliggende bolig (fritliggende enfamiliehus); Sammenbyggede boliger (fx dobbel-, række- og kædehuse); Etagebolig, Lager mv eller Andet (ikke bolig)

0	Antal boligenheder	0	Rotation, °
180	Opvarmet etageareal, m²	0	Andet, m²
120	Varmekapacitet, Wh/K m²	Start, kl.	Slut, kl.
168	Normal brugstid, timer/uge	0	24

Beregningsbetingelser

Mærkning — Se beregnings-vejledningen

Tillæg til energirammen for særlige betingelser, kWh/m² år: 0

(Kun mulig for andre bygninger end boliger og beregningsbetingelser: BR: Aktuelle forhold)

Varmeforsyning

El — Basis: Kedel, Fjernvarme, Blokvarme eller El

☑ Varmefordelinganlæg (hvis elvarme)

Bidrag fra (i prioritets-orden)

☐ 1. Elradiatorer ☐ 2. Brændeovne, gasstrålevarmere og lign.

☐ 3. Solvarme ☑ 4. Varmepumpe ☐ 5. Solceller ☐ 6. Vindmøller

Mekanisk køling

0 Andel af etageareal, -

Beskrivelse

Kommentarer

Samlet varmetab

Transmissionstab 3,6 kW 19,9 W/m²

Ventilationstab uden vgv 2,1 kW 11,6 W/m² (om vinteren)

I alt 5,7 kW 31,5 W/m²

Ventilationstab med vgv 2,1 kW 11,6 W/m² (om vinteren)

I alt 5,7 kW 31,5 W/m²

Transmissionstab

For klimaskærmen ekskl. vinduer og døre

4,3 W/m²

Åbnet ny model

Energibehov 58,1 kWh/m² år. Energiramme BR 2010: 61,7 Lavenergi 2015: 35,6 Bygninger 2020

Be10 calculation

Check that the building is inside the energy frame

Heat demand x EF
+ Electricity x EF
– Renewable Energy
+ Overheating Penalty < Energy Frame

EF a primary energy factor for the used energy
(can be both below and above 1)

Fuel conversion factors
Primary energy factors

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Conversion factors to primary energy are changed in coming Danish Building Regulations

	2010	2015	2020
Electricity	2.5	2.5	1.8
District heating	1.0	0.8	0.6
Fossil fuels, incl. bio	1.0	1.0	1.0

Thermal indoor climate

- In buildings complying with the low energy class 2015 or the building class 2020, the thermal indoor climate must be documented via calculations
- In dwellings, institutions, offices etc. the thermal indoor climate must not exceed 27°C, except during a limited number of hours compared with the reference year
- Documentation for the thermal indoor climate can be done according to DS474
- For dwellings proof can be provided via a simplified calculation in Be10

Max overheating hours pr year

Year	Number of hours above 27 °C	Number of hours above 28 °C
2010	No rules	No rules
2015	< 100	< 25
2020	< 100	< 25

New 2015 climate data

Overview important for new buildings

- Extra insulation in walls and roof
- Use of highly insulated windows
- Reduction of thermal bridges
- Use materials with high thermal inertia to reduce problems with overheating
- Building airtight
- Optimal use of solar radiation and daylight, including orientation of the building
- Energy efficient ventilation with heat recovery

Status 2010 future houses

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

FREMTIDENS PARCELHUSE

Afrapportering til

Energiforskningsprogrammet 2007

Det Grønne Hus i samarbejde med SBi

Erfaringsopfølgning på lavenergibyggeri klasse 1 og 2.

- med "Fremtidens Parcelhuse" som eksempel

Den kompakte form
Grundrids
2 plan

Orientering af vinduer
Nord 6m²
Syd 6m²
Øst 6,6m²
Vest 13,7m²

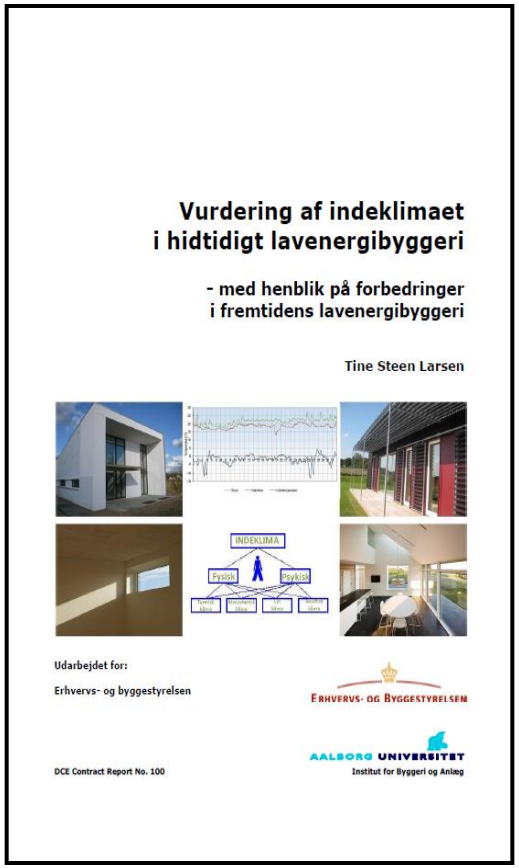
Isolering
Loft-gulv 0,10 W/m²K
Vægge 0,15 W/m²K
Vinduer 0,8-0,9 W/m²K

Linietab
Fundament 0,08
Vinduer 0,03

Udarbejdet af:

Lars Kristensen og Ole Michael Jensen (red.)
Bidrag fra: Heidi Arvedsen (DGH), Niels Christian Bergsøe (SBi), Ole Michael Jensen (SBi), Henrik N. Knudsen (SBi), Jesper Kragh (SBi), Lars Kristensen (DGH), Tommy Olsen (DGH), Torben Valdbjørn Rasmussen (SBi)

SBi · Energitjenesten · Det Grønne Hus



Vurdering af indeklimaet
i hidtidigt lavenergibyggeri

- med henblik på forbedringer
i fremtidens lavenergibyggeri

Tine Steen Larsen

INDEKLIMA
Fysisk
Psykisk

Udarbejdet for:

Erhvervs- og byggestyrelsen

Erhvervs- og Byggestyrelsen

DCE Contract Report No. 100

Aalborg Universitet
Institut for Byggeri og Anlæg

- **Too high temperatures in summer (overheating)**
- Too low temperatures in winter
- Noise from technical installations
- Need for more robust and easy-to-use technical installations that are fully operational at the time of moving into the house

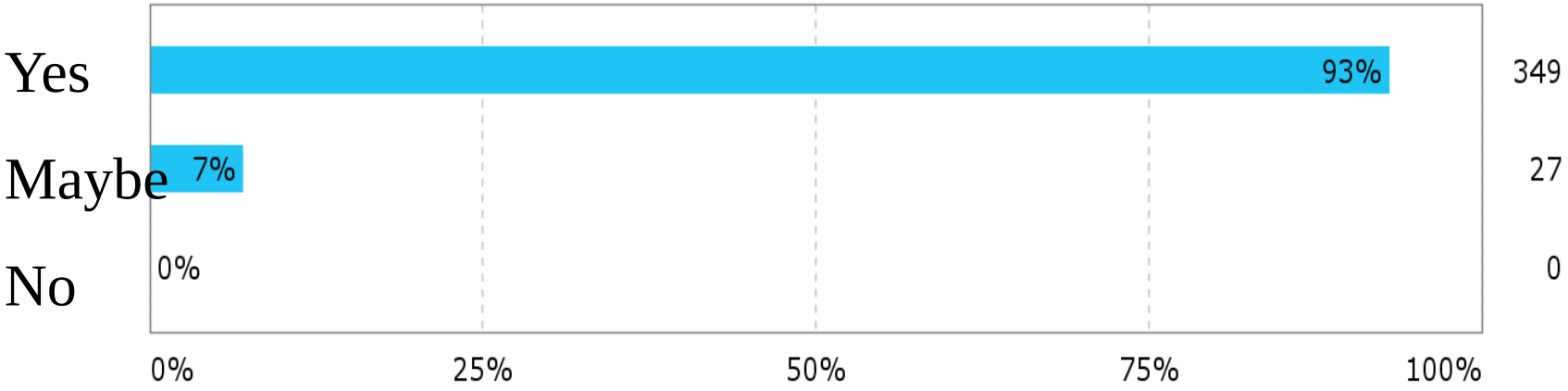
2015 new investigation

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

- Low-energy class 2015 (Building Regulations 2010)
- Based on 370 answers of questionare
- Average size: 186 m^2
- Heat pump (65%)
- Ventilation systems with heat recovery (76%)
- Floor heating (94%)
- Photo Voltage (71%)

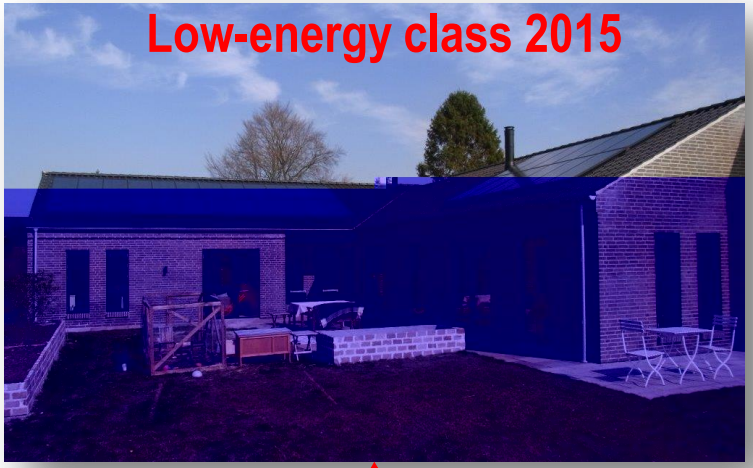
Overall satisfaction

Can you recommend others to live in a low-energy house?



Indoor climate in new house compared with former dwelling?

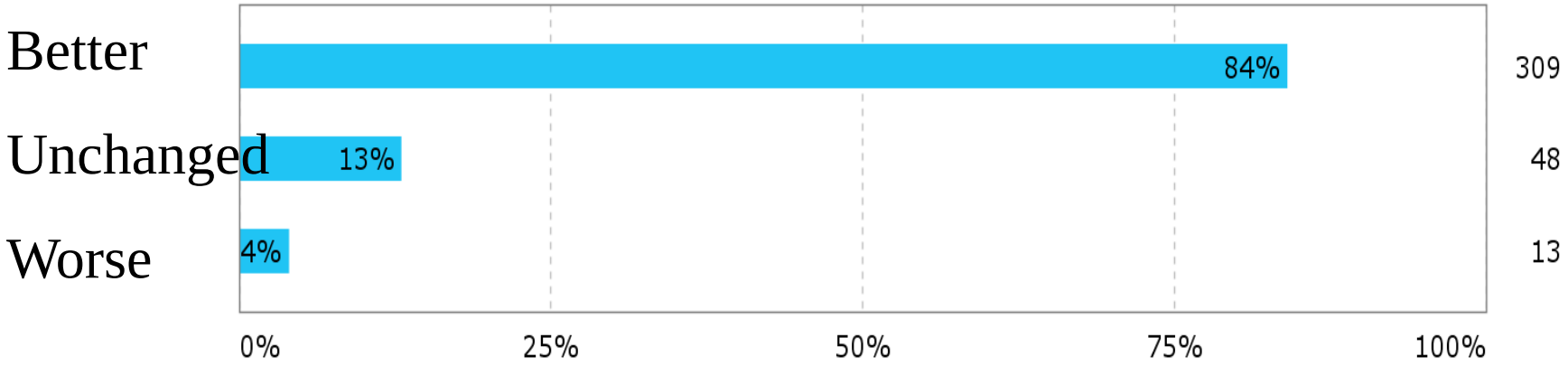
DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN



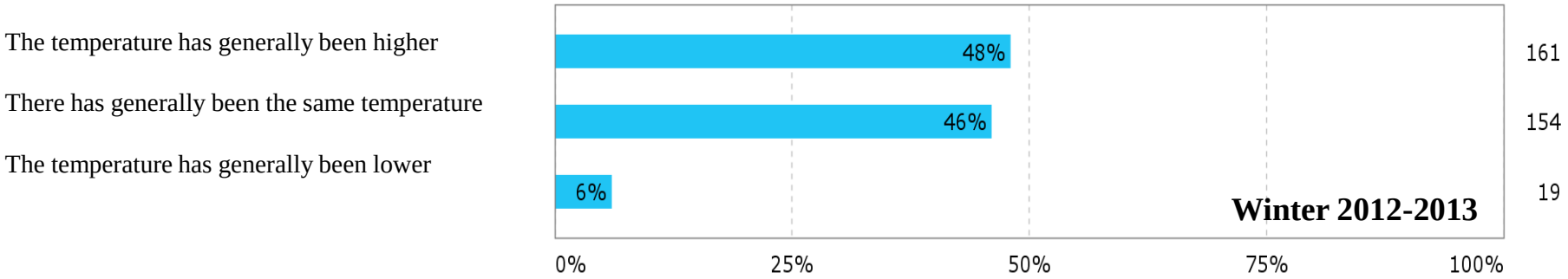
Former dwelling

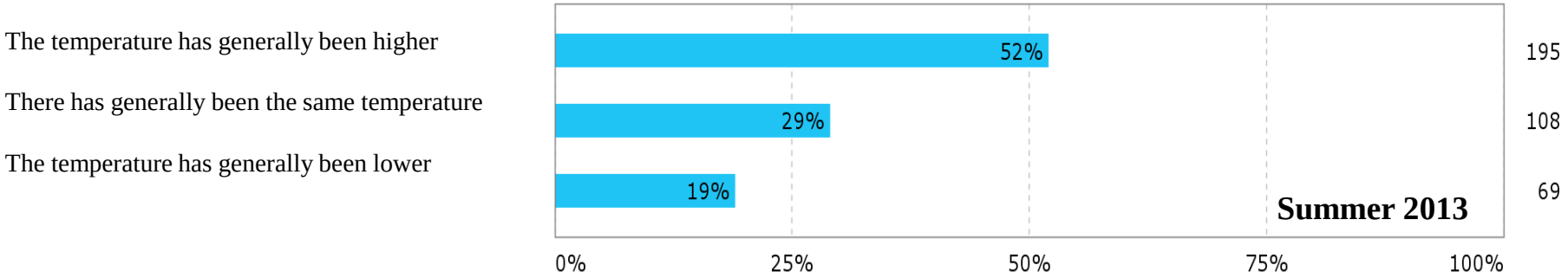
New house

How do you find **temperature conditions** in your new house compared with your previous dwelling?

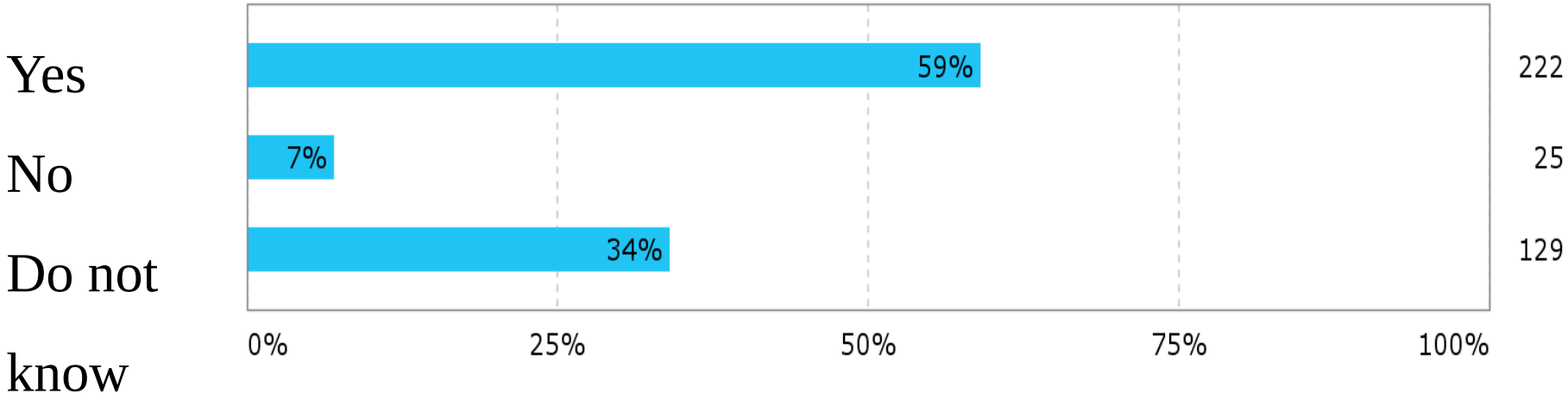


How has the **temperature** been in your new house in **winter/summer** compared with your previous dwelling?





Is the **heat consumption** as low as you expected before you moved into the house?

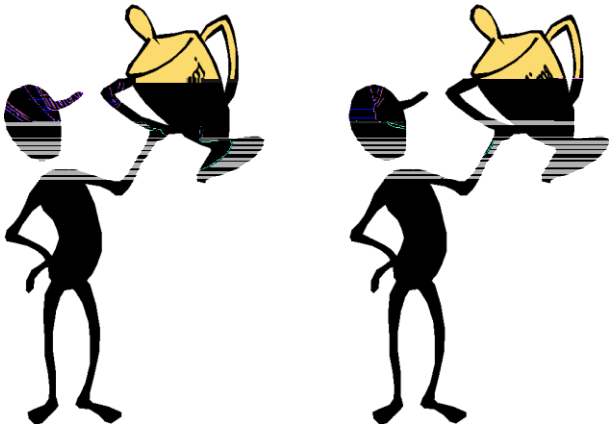


Conclusions

Overall satisfaction with low-energy houses

The indoor climate is perceived positively

- Problems with overheating in earlier generations of low-energy houses seems to have been partly solved by the low-energy class 2015 temperature requirements



CALCULATED AND MEASURED ENERGY CONSUMPTION

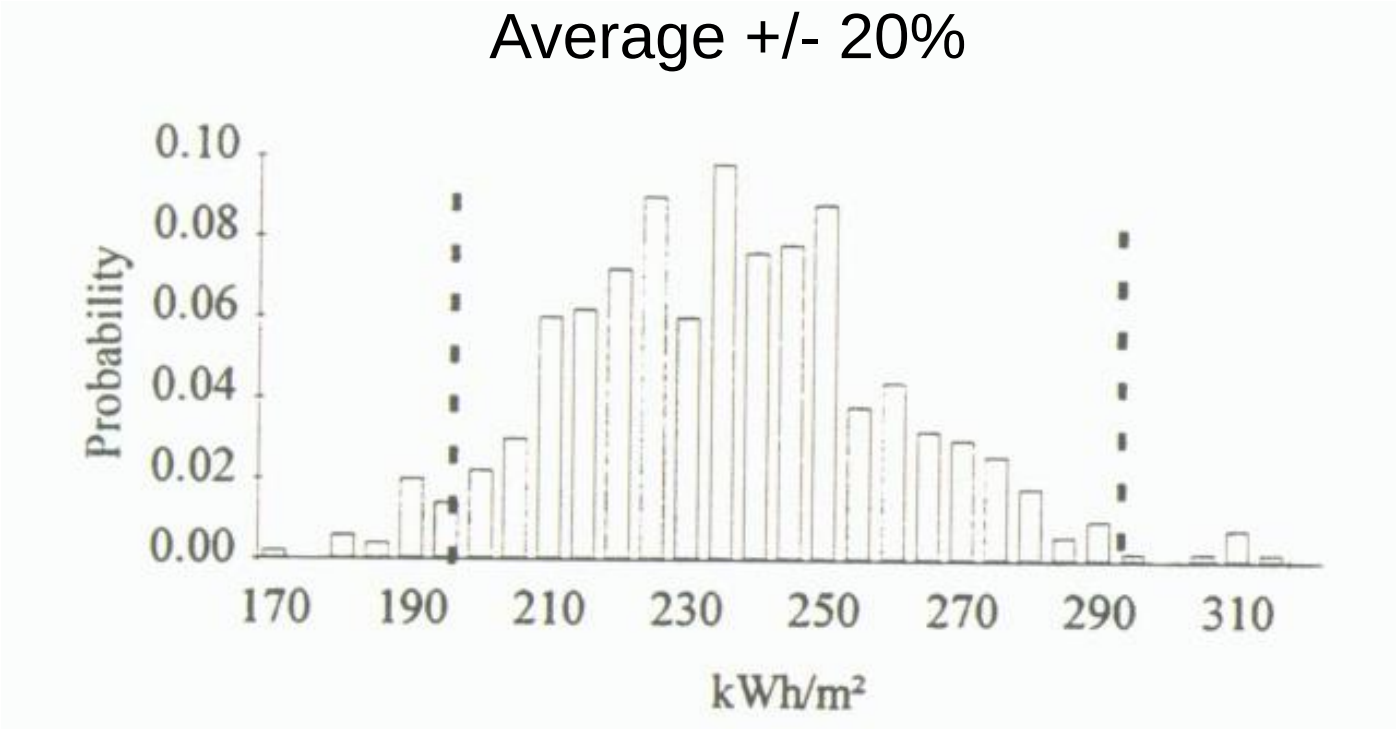
DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Real energy consumption

- Most people prefer 22C and not 20C as in the rules
- + 2C gives around 16% total higher energy consumption
- Fewer persons in family or not so much home
- More or less free heat
- Air change from ventilation or open doors and windows

Example of typical variations in energy consumption (500 cases)

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

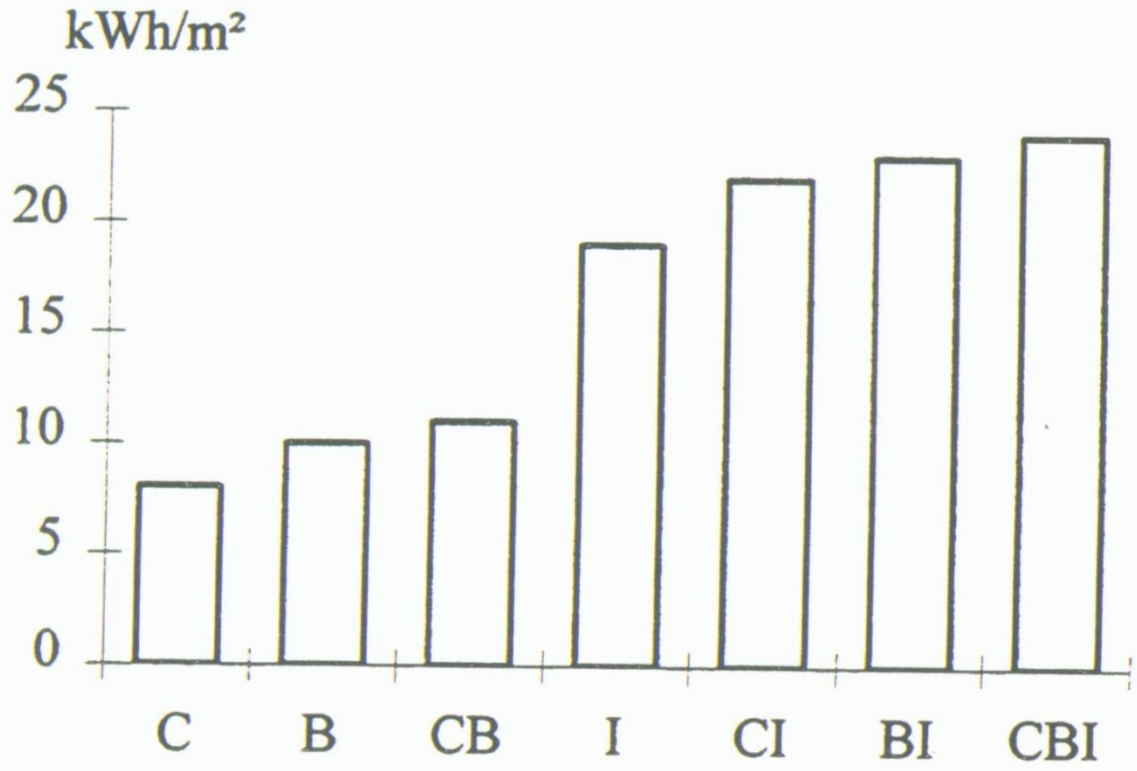


Standard deviation for different variables

C = climate

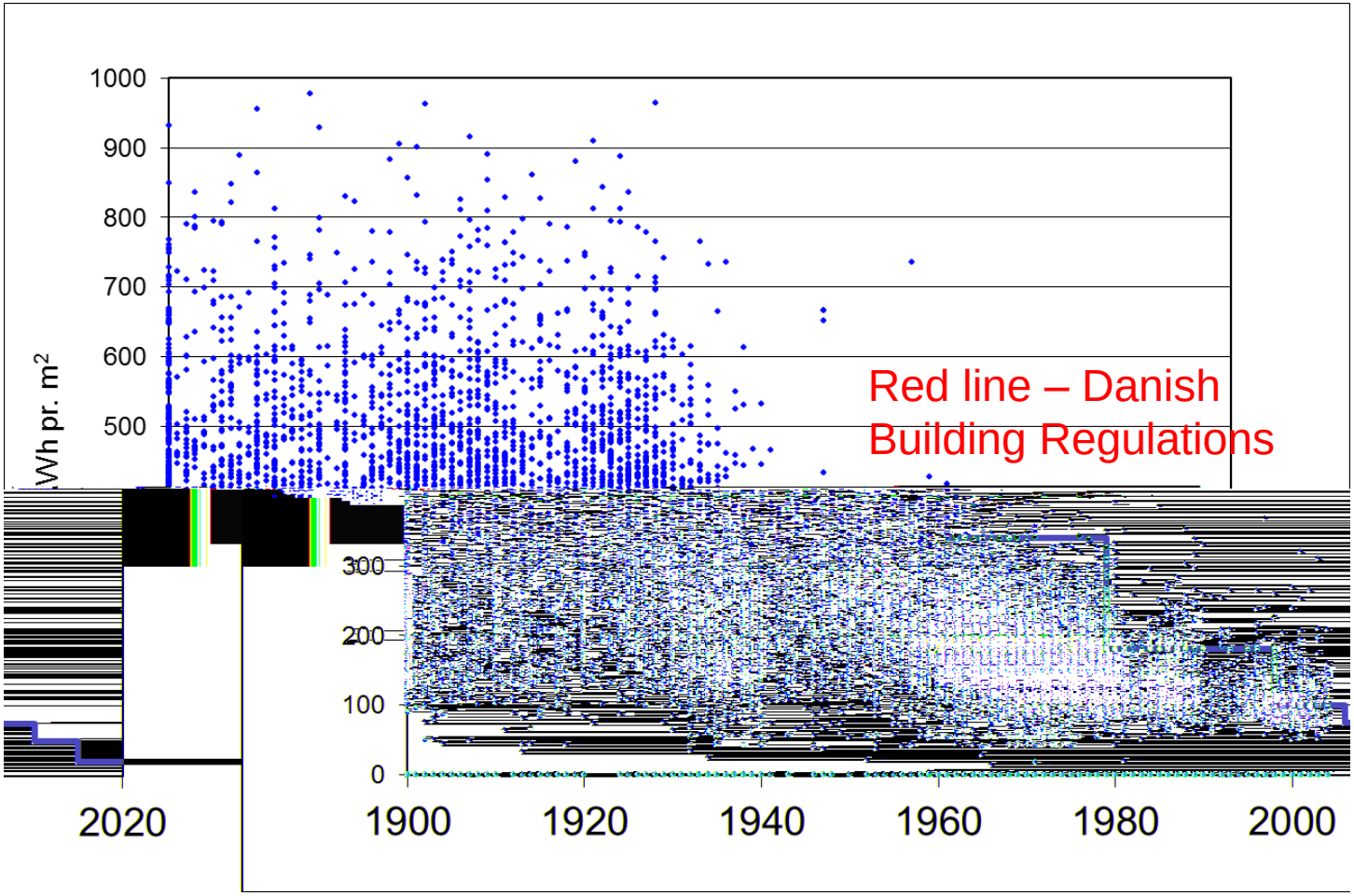
B = building

I = inhabitants



Measured energy demand in Danish houses

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN



Single family house – savings 10% for each 1 C lower indoor temperature

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Blocks of flats
Hedeparken 1960 – industrialised building

Indgangsfacade

Gavl og altanfacade

Energy demand of flats MWh/year

4	11.2	5	9	9.6	13	9.6	14	18	9.6	22	9.6	23	27	9.6
3	7.4		8	5.9	12	5.9		17	5.9	21	5.9		26	5.9
2	7.4		7	5.9	11	5.9		16	5.9	20	5.9		25	5.9
1	10.4		6	8.9	10	8.9		15	8.9	19	8.9		24	8.9
28														

All flats 2C lower temperature – 20% savings

Left = flat number
Right = energy demand in MWh/year

Energy balance

For a single flat

- Heat flow to outdoor climate - external walls, floors and roofs
  - Transmission
  - Ventilation
  - Solar radiation
- Heat flow to surrounding flats – interior walls and floors
  - Above
  - Below
  - Right
  - Left

Example – centre flat 2 C lower indoor temperature

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

	Original	Insulation between flats	Realistic
Flat 7	-71%	-40%	-58%
Flat 8 above	18%	10%	14%
Flat 6 below	13%	7%	10%
Flat 2 left	7%	2%	5%
Flat 11 right	16%	4%	13%

Energy Savings

If all lowered the temperature 2 C then 20% savings

Single family house 20%

Single flat in block max 70% - min 0%

Depending on neighbours behaviour

MOISTURE IN HIGHLY INSULATED CONSTRUCTIONS

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Moisture in highly insulated constructions

SBi study based on

- Litterature
- Calculations
- Measurements

Wall construction

- Outer part colder
- Higher humidity in outer part
- A wooden outer panel will be more wet
- The drying out will take more time
    - Building moisture
    - Driving rain
    - Leakage

- Calculations from Sweden of different cases
    - 220 mm insulation
    - 520 mm insulation

Relativ Humidity (RF) with 220 mm

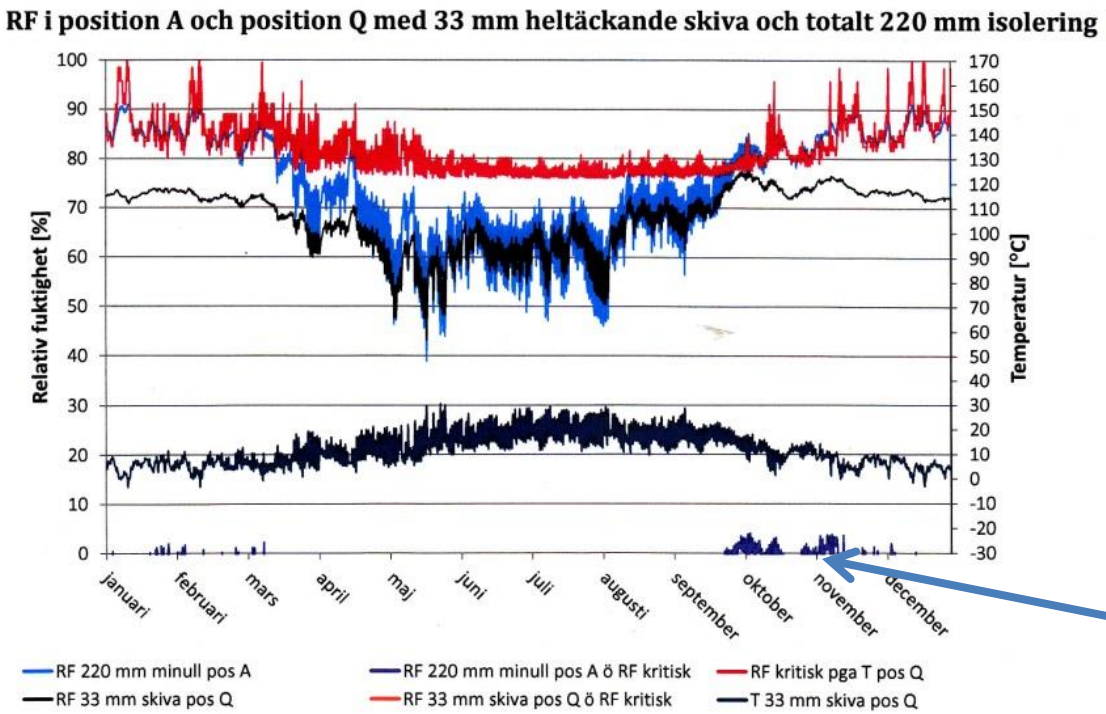


Diagram 36. RF i position Q (svart), RF i position A, samma som utgångsfall, (turkos), RF_{krit} (röd), temperatur (mörkblå), RF position Q över RF_{krit} (ljusblå), RF position A över RF_{krit} (lila), samma som utgångsfall.

Periods with mould risk

Relative Humidity (RF) with 520 mm

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

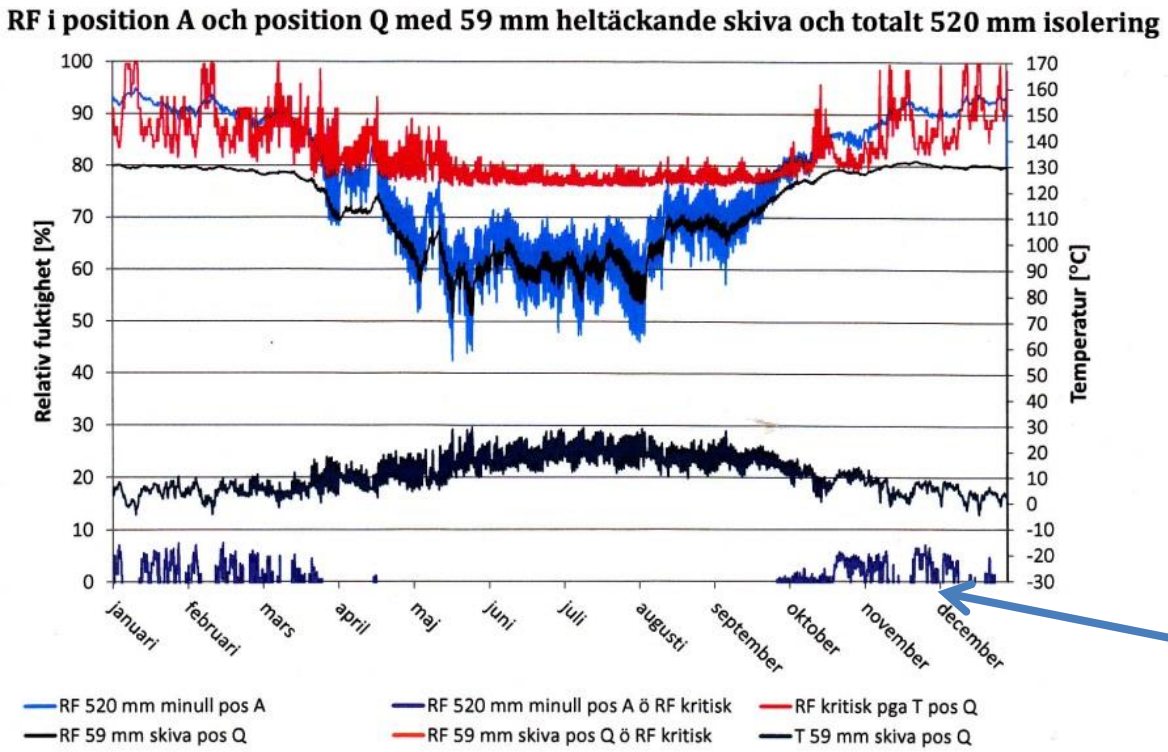


Diagram 42. RF i position Q (svart), RF i position A (turkos), RF_{krit} (röd), temperatur (mörkblå), RF position Q över RF_{krit} (ljusbrun), RF position A över RF_{krit} (lila).

Periods with mould risk
- Longer with 520 mm

Roof construction

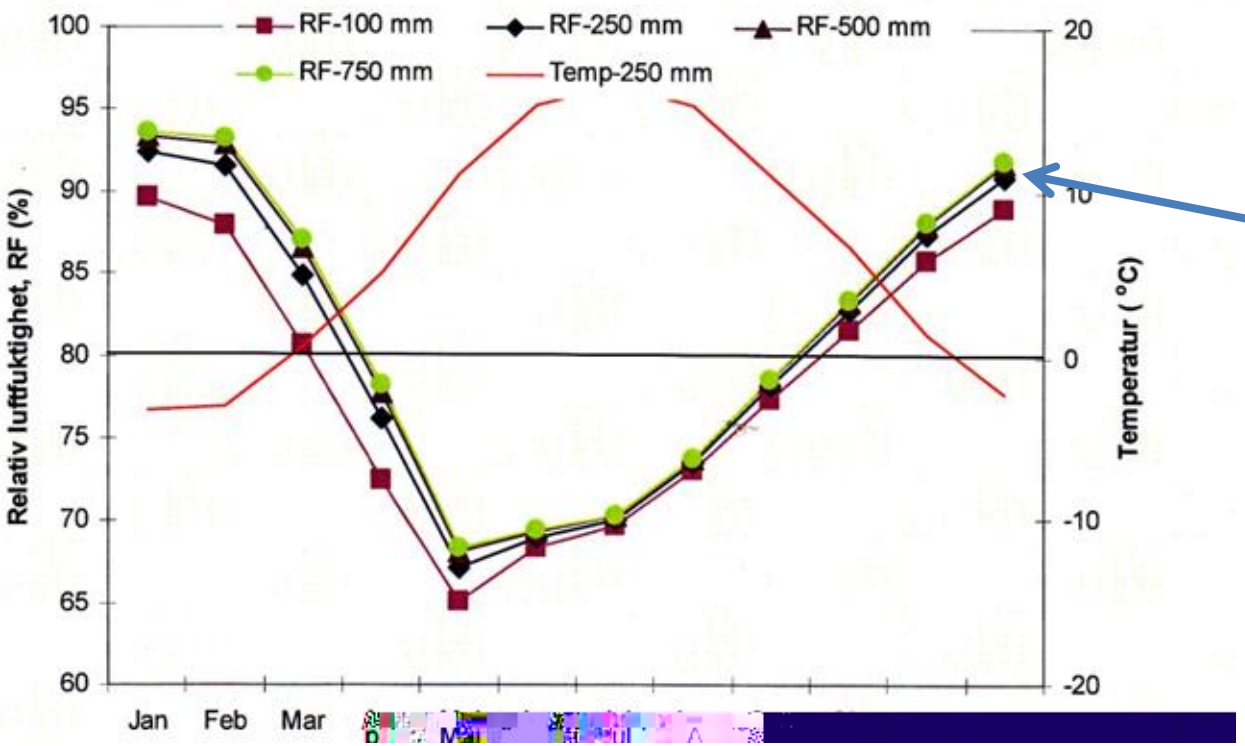
Ventilated roof construction

- Much used construction in todays houses
- The air temperature in the attic will not change very much for more insulation at the attic floor

Norwegian calculation of roofs with

- 100 mm
- 250 mm (todays practise)
- 500 mm
- 750 mm

Relative humidity(RF) in ventilated roof
Norwegian calculation



Same for
250 mm
500 mm
750 mm

Moisture in highly insulated constructions

- Lower temperature of the outer surface
- Slightly increased risk for moisture
- Drying out is slower

Important

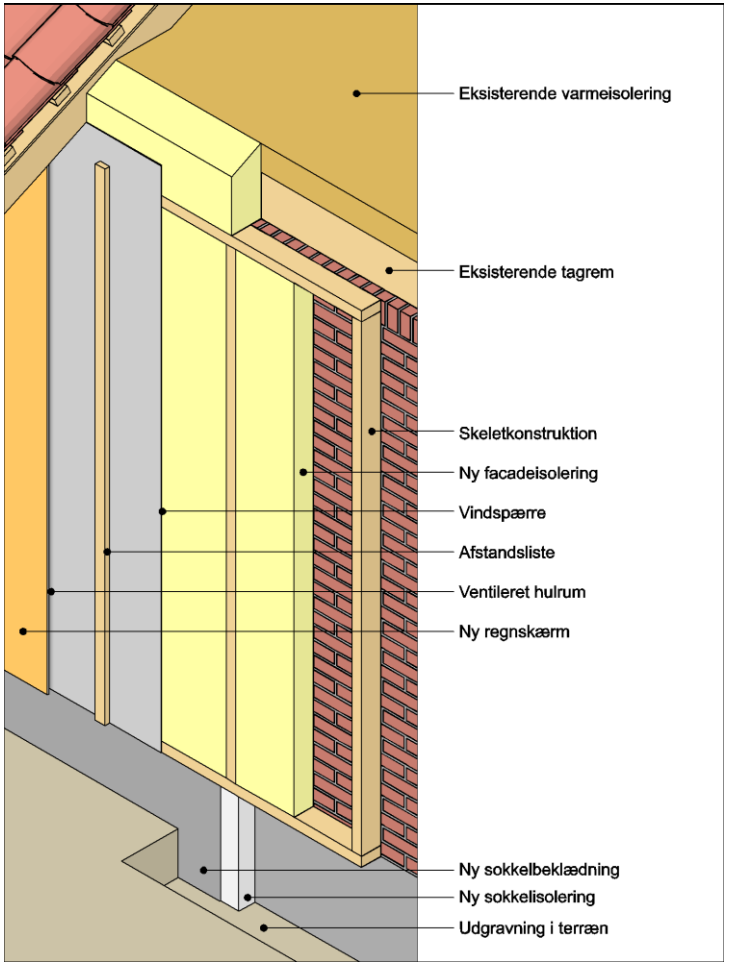
- **Keep moisture out in the building period**
- **Build airtight – MAKE CONTROL**
- **Follow moisture design guidelines**

EDUCATION
MASTER IN BUILDING PHYSICS

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Why Master in Building Physics ?

- Need to reduce the energy consumption in the existing building stock
- Many building damages come from moisture.
- A better moisture design is much needed. Before only short courses.
- Master in Building Physics is an accredited education (approved by the ministry) that provides formal qualifications.
- The program is research based, which among other things means that the student meets the leading experts in the field.
- Most teachers come from the SBi and are also involved in writing Directions for the Danish Building Regulations



Time and price

Time

- 2 year on half time; equivalent 60 ECTS point
- Period September 2015 - June 2017
- Start once a year

Price

- Whole Master in Building Physics: 13.000 €. (4 x 3.250 €.)
- Single courses á 5 ECTS point: 1.100 €.

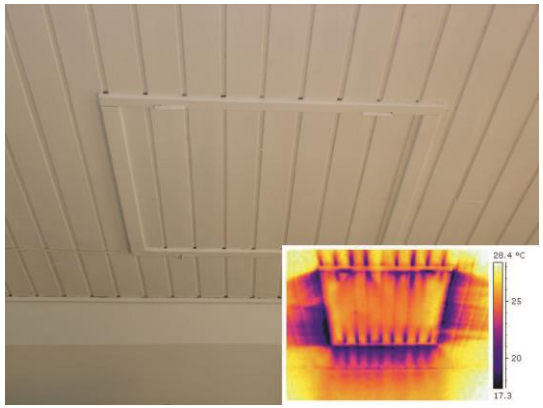
All courses in Danish

1. semester: Basis – theory and practice

Heat (5 ects)

Moisture(5 ects)

Air tightness and ventilation (5 ects)



- $\Phi = \lambda \cdot \frac{A}{d} \cdot \Delta\theta$ $\quad q = \frac{\Phi}{A} = \lambda \cdot \frac{\Delta\theta}{d}$
- Varmestrøm [W] Varmestrømstæthed [W/m²]
  - λ = varmeledningsevne [W/(m K)]
  - A = areal [m²]
  - d = tykkelse [m]
  - $\Delta\theta$ = temperaturforskel [°C]
- Forudsætter stationære forhold: temperaturer og fugtforhold konstant

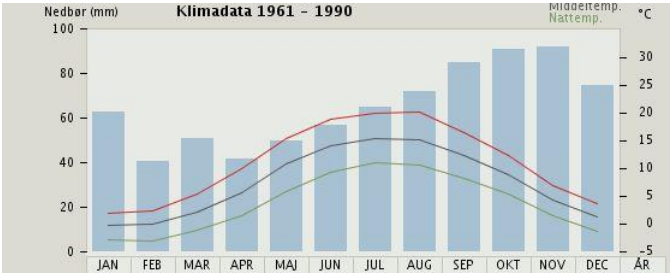
- Air can contain moisture like any other gas
- Warm air can contain more moisture than cold air

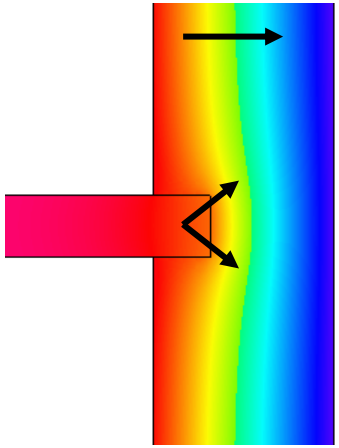
Connection between:

2. semester: Calculations

Indoor and outdoor climate(5 ects)
Energy, Heat and moisture calculations (10 ects)

Be 10, BSIM. Heat 2, WUFI





One-dimensional heat flow

Two-dimensional heat flow cold brigde

3. semester: Practice

Condition Assessment, Building Failures, Re-insulation and Refurbishment(10 ects)

New buildings –
new materials and solutions (5 ects)

Entry requirements

At least two years of relevant work experience in construction and building technology

Basic education:

- Master of Science in Engineering
  (building technology)
- Bachelor of Engineering
  (building technology)
- Bachelor in Architectural Technology and Construction Management.
- Architect
  (Building technology)

1. semester – autumn

September	October	November	December	January
36	40	45	49 3 week	1
37 1 week	41	46	50	2 examination
38	42	47	51	3
39	43	48	52	4
	44 2 week		53	

Education week

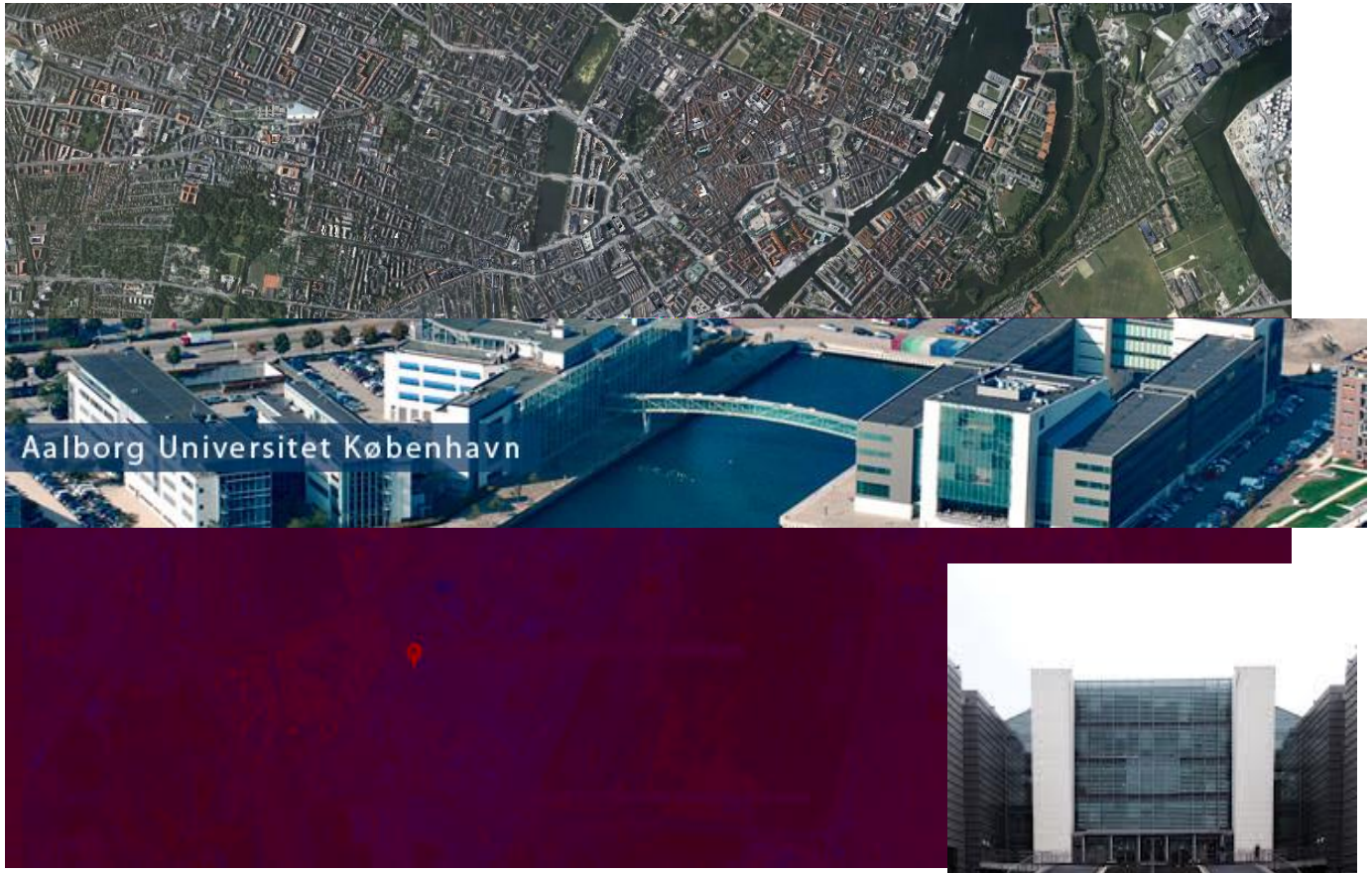
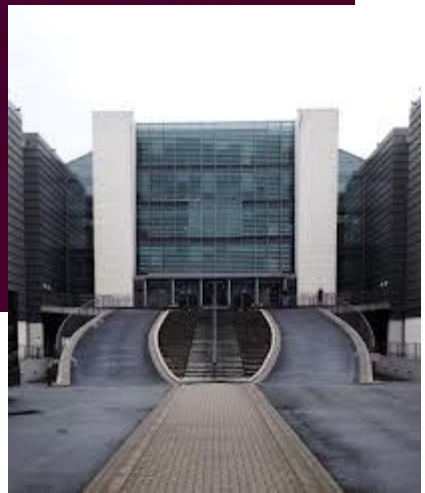
Time	Monday	Tuesday	Wedensday	Thursday	Friday
8.00-11.45	Heat teory and practice	Heat teory and practice	Moisture theory	Air tightness and ventilation	Air tightness and ventilation
12.30-16.30	Heat teory and practice	Moisture theory	Moisture theory	Air tightness and ventilation	

Summary

- The Danish Building Regulations has rules energy efficient houses for the future.
- The building industry can prepare for the new rules in 2020
- A standard program Be10 is used to control the energy frame
- The real energy consumption can be different from the theory.
- The inhabitant are the mostly responsible for differences.

- New building with thicker insulation will dry out more slowly, but the risk is low if moisture guidelines are followed.

- A new part time education for energy savings and moisture design (Master in Building Physics).

Aalborg University Copenhagen

SYDHAVN