TEKNIK OG MILJØ
Aarhus Kommune

Varmebesparelser vha. data-drevet modellering af den eksisterende bygningsmasse

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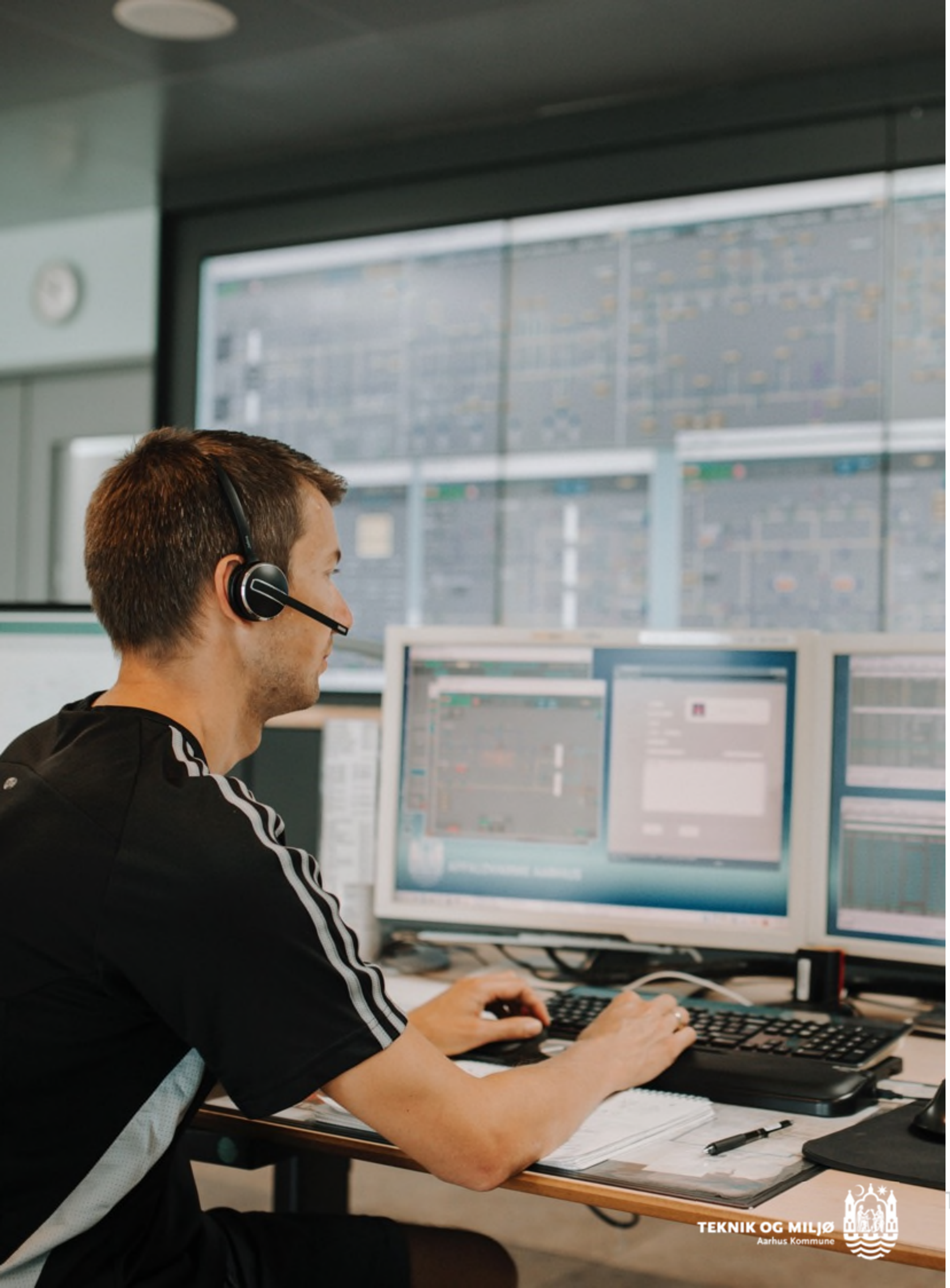
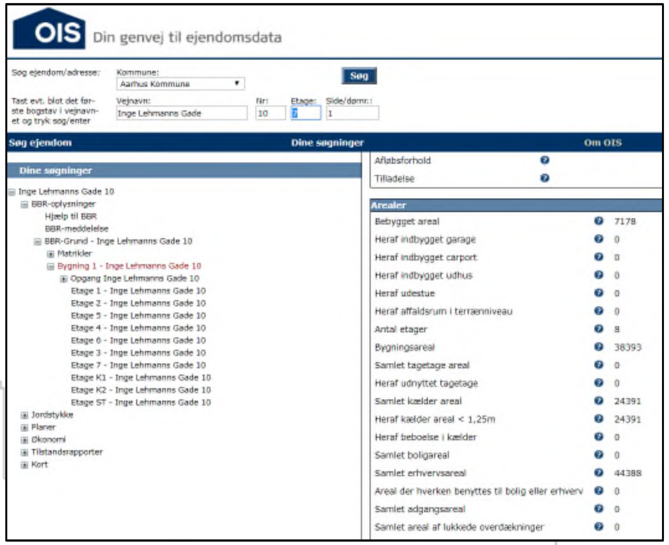
DAGSORDEN

1. Direkte analyse af målerdata
2. Bygningsmodellering ved brug af målerdata
3. Applikations-eksempel
4. Opsamling



Hvilke data snakker vi om?

- Timeaflæsninger fra ca. 60.000 kunder i Aarhus (komplette datasæt fra ca. 2017 og frem)
  - Fjernvarmeforbrug
  - Afkøling
- BBR data om de enkelte bygninger
  - Anvendelseskoder, byggeår, arealer, etager, varmekilder, osv.



Nuværende praksis

Hvordan dimensioneres fjernvarmeledninger?

- Antagelser om energiforbrug i bygninger:
  - Nybyggeri: Typisk bygningsreglementets energirammekrav + 50% usikkerhed…
  - Eksisterende byggeri: Typisk et "standardhus" på 130m^2 med et forbrug på 11 MWh/år.
- Beregning af effekt:
  - Anvendelse af "fuldlasttimer" til at veksle mellem årsforbrug (MWh) og spidseffekt (MW).
  - Typisk anvendes et historisk nøgletal på 2900 fuldlasttimer pr. år for den eksisterende bygningsmasse, men hvordan ser det ud for nybyg?

Nyt boligområde på 3.000 m2 og en bebyggelsesprocent på 140%

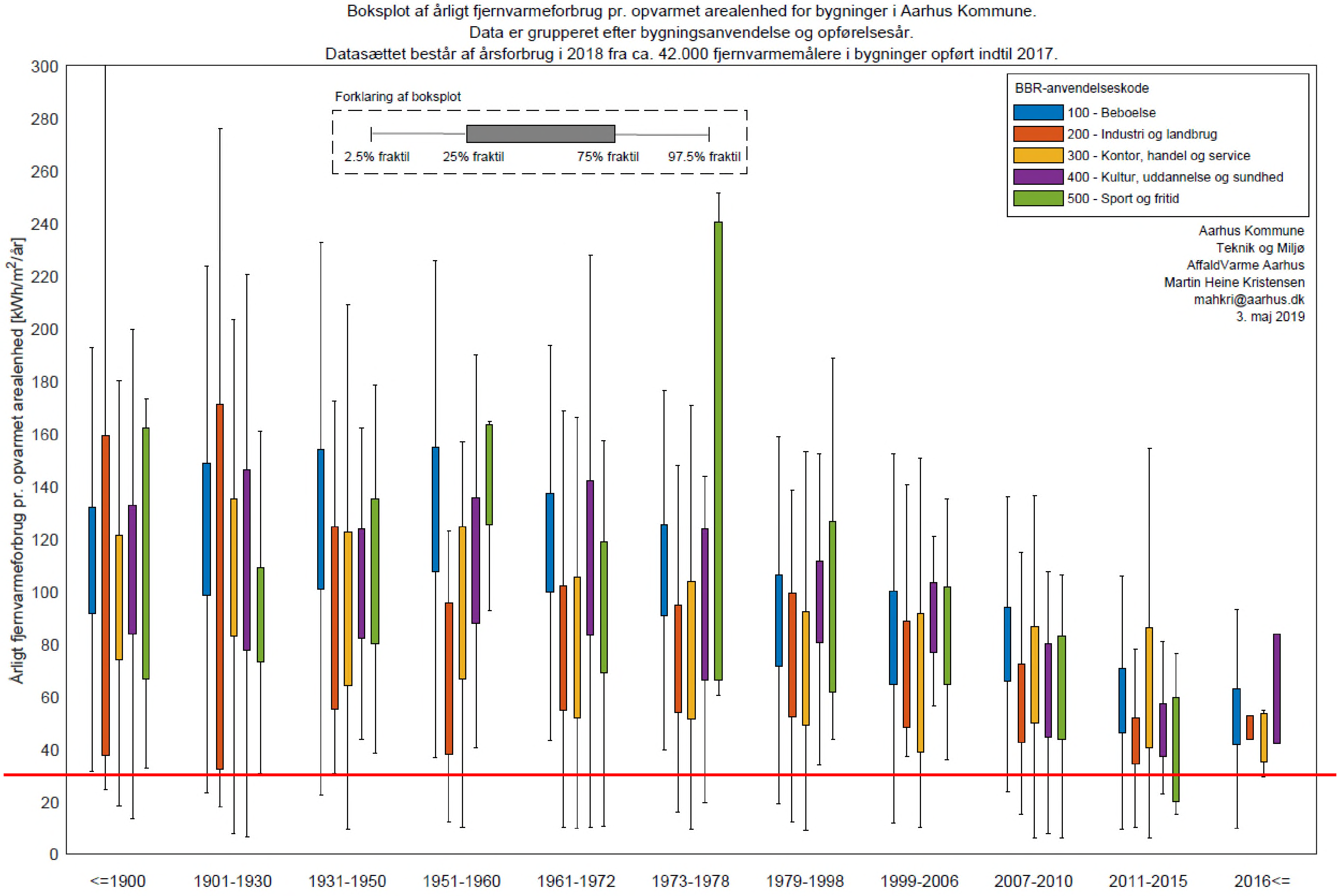
Areal:
1. 3.000 m2 · 140% = 4.200 m2 (bebyggelse)
2. 4.200 m2 · 150% = 6.300 m2 (+ 50% usikkerhed)

Energi:
1. (30 + 1000/6.300) = 30,2 kWh/m2 (Energiramme)
2. 30,2 kWh/m2 · 150% = 45,2 kWh/m2 (+50% usikkerhed)
3. 45,2 kWh/m2 · 6.300 m2 = 285 MWh

Dimensionerende effekt:
1. 285 MWh / 2.500 h = 114 kW (fuldlasttimer)
2. 114 kW · 130% = **148 kW** (+30% usikkerhed)

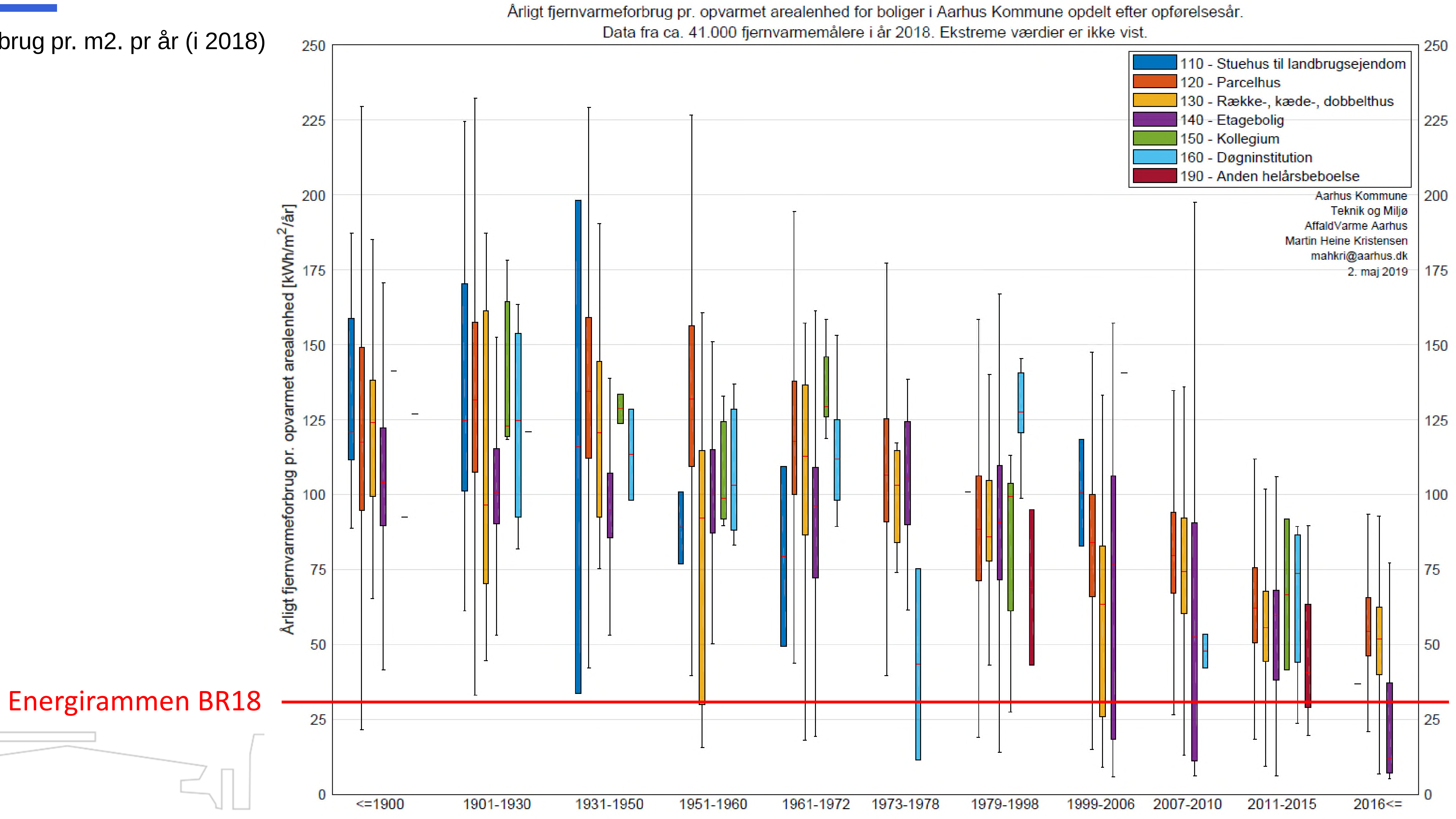
Et overblik over bygningsmassen

Energiforbrug pr. m2. pr år (i 2018)



Et overblik over bygningsmassen

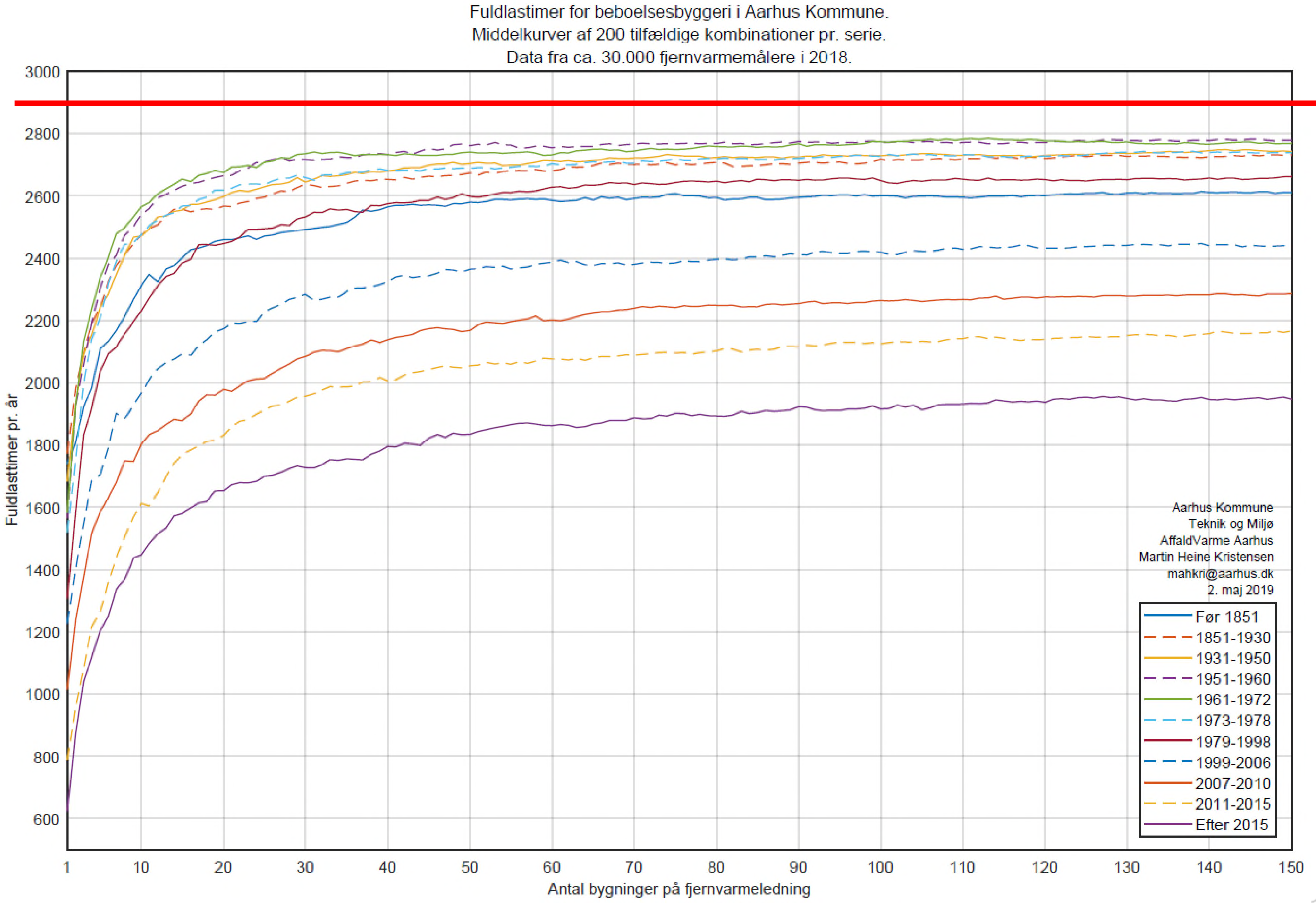
Energiforbrug pr. m2. pr år (i 2018)



Et overblik over bygningsmassen

Fuldlasttimer

<u>Antal fuldlasttimer [h]:</u>
Årsforbrug [kWh] divideret med største timeffekt [kW]



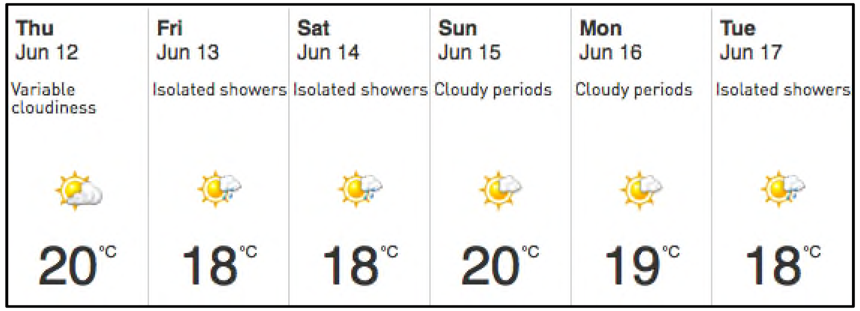
Hvordan kan vi ellers bruge de mange forbrugsmålinger?

Formål

1. At lave et simuleringsværktøj til at generere varmeprognoser af bygningsmassens fjernvarmeforbrug.

2. Modellen skal kunne bruges til at evaluere varmebehovet på både kort sigt (dage/uger) og lang sigt (2050?).

3. Modellen skal kunne bruges til at analysere effekterne på den nødvendige fjernvarmeproduktion ved forskellige interventioner i bygningsmassen, fx renovering og nybyg.



Umiddelbare erkendelser

- Modellen skal funderes på en ”bottom-up” beskrivelse af det varmeforbrug der finder sted i hvert eneste hus i byen.
- Modellen skal trænes på en større mængde eksisterende/historisk timedata for at kunne ”regne rigtigt” i fremtiden.
- Modellen skal være simpel og skalérbar for at kunne bruges i praksis.

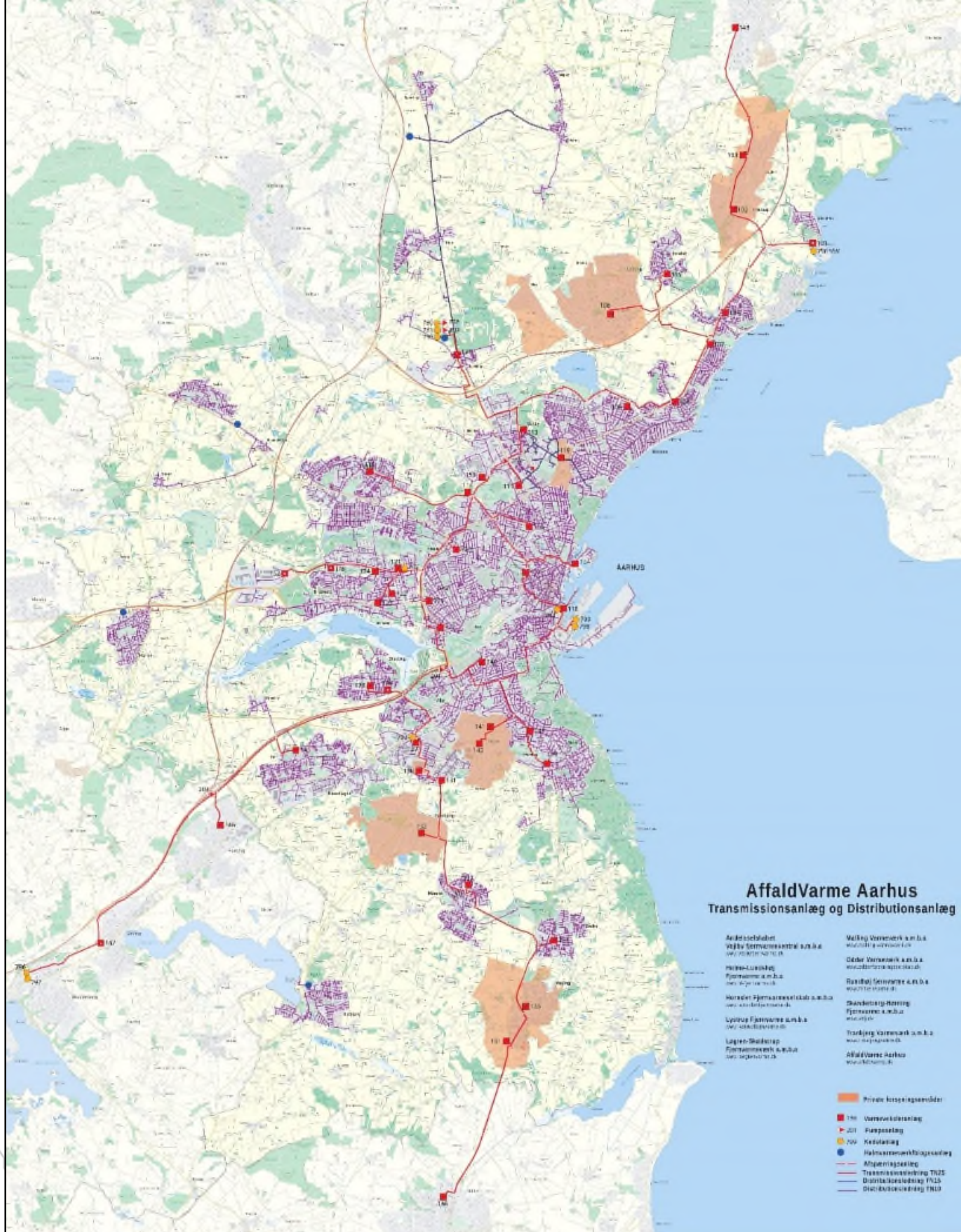
Case data

- 23.000 parcelhuse

- To års målt fjernvarmeforbrug pr. hus (2017 + 2018)
  - Trænings-data: 2017
  - Test-data: 2018

- BBR-data for hvert hus (anvendelse, byggeår, areal, osv.)

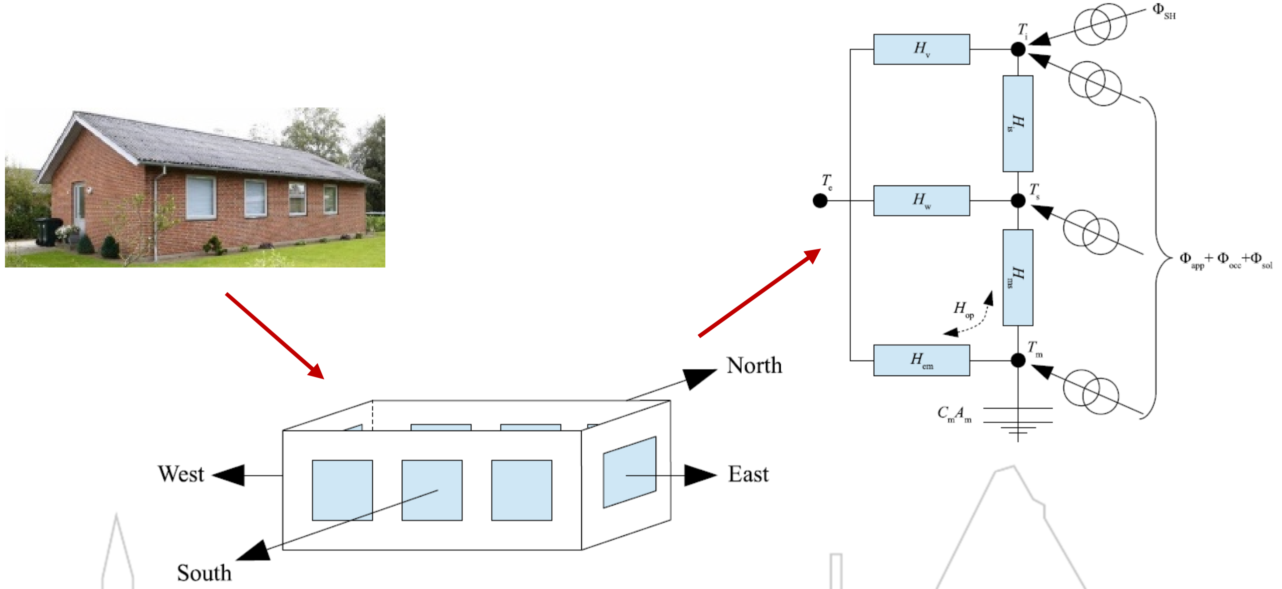
- Målt vejrdata (solindstråling og lufttemperatur)



Metode (1/2)

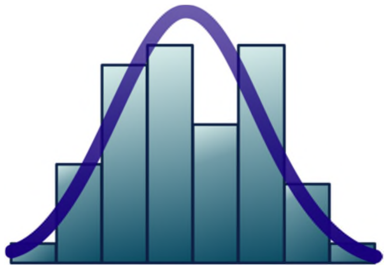
Archetype, *k*	Example	Building period	Segmentation argument
Archetype 1		Before 1851	
Archetype 2		1851-1930	Shift in building tradition
Archetype 3		1931-1950	Cavity walls introduced
Archetype 4		1951-1960	Insulated cavity walls introduced
Archetype 5		1961-1972	First energy requirements in BR1961
Archetype 6		1973-1978	Tightened energy requirements in BR1972
Archetype 7		1979-1998	Tightened energy requirements in BR1978.
Archetype 8		1999-2006	Tightened energy requirements in BR1998.
Archetype 9		2007-2010	Tightened energy requirements in BR2006/BR2008
Archetype 10		2011-2015	Tightened energy requirements in BR2010
Archetype 11		After 2015	Tightened energy requirements in BR2015

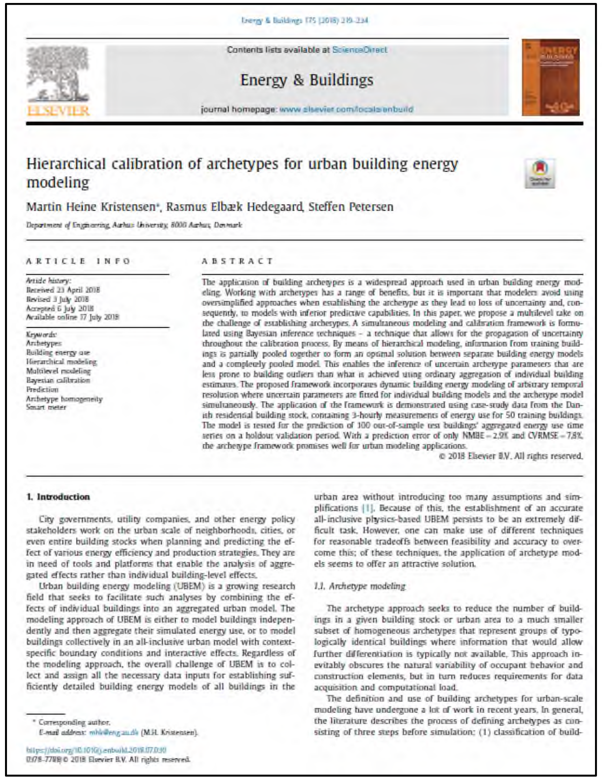
- Bygningsmassen inddeles i 11 arketyper
- Alle bygninger tildeles en geometrisk model, en rumvarmemodel og en brugsvandsmodel



Metode (2/2)

- Hver eneste bygningsmodel har ca. 25 usikre input parametre!
- Usikre parametre antages at være ”identiske” for alle bygninger i den samme arketype.
- For hver arketype kalibreres 8 usikre parameterværdier vha. en stokastisk metode.
- Hver arketype kalibreres vha. timedata fra 100 tilfældige træningsbygninger

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Hierarchical calibration of archetypes for urban building energy modeling

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ABSTRACT

The application of building archetypes is a widespread approach used in urban building energy modeling. Working with archetypes has a range of benefits, but it is important that modelers avoid using oversimplified approaches when establishing the archetype as they lead to loss of uncertainty and, consequently, to models with inferior predictive capabilities. In this paper, we propose a multilevel take on the challenge of establishing archetypes. A simultaneous modeling and calibration framework is formulated using Bayesian inference techniques – a technique that allows for the propagation of uncertainty throughout the calibration process. By means of hierarchical modeling, information from training buildings is partially pooled together to form an optimal solution between separate building energy models and a completely pooled model. This enables the inference of uncertain archetype parameters that are less prone to building outliers than what is achieved using ordinary aggregation of individual building estimates. The proposed framework incorporates dynamic building energy modeling of arbitrary temporal resolution where uncertain parameters are fitted for individual building models and the archetype model simultaneously. The application of the framework is demonstrated using case-study data from the Danish residential building stock, containing 3-hourly measurements of energy use for 50 training buildings. The model is tested for the prediction of 100 out-of-sample test buildings' aggregated energy use time series on a holdout validation period. With a prediction error of only NMBE = 2.9% and CVRMSE = 7.8%, the archetype framework promises well for urban modeling applications.

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1. Introduction

City governments, utility companies, and other energy policy stakeholders work on the urban scale of neighborhoods, cities, or even entire building stocks when planning and predicting the effect of various energy efficiency and production strategies. They are in need of tools and platforms that enable the analysis of aggregated effects rather than individual building-level effects.

Urban building energy modeling (UBEM) is a growing research field that seeks to facilitate such analyses by combining the effects of individual buildings into an aggregated urban model. The modeling approach of UBEM is either to model buildings independently and then aggregate their simulated energy use, or to model buildings collectively in an all-inclusive urban model with context-specific boundary conditions and interactive effects. Regardless of the modeling approach, the overall challenge of UBEM is to collect and assign all the necessary data inputs for establishing sufficiently detailed building energy models of all buildings in the urban area without introducing too many assumptions and simplifications [1]. Because of this, the establishment of an accurate all-inclusive physics-based UBEM persists to be an extremely difficult task. However, one can make use of different techniques for reasonable tradeoffs between feasibility and accuracy to overcome this; of these techniques, the application of archetype models seems to offer an attractive solution.

1.1. Archetype modeling

The archetype approach seeks to reduce the number of buildings in a given building stock or urban area to a much smaller subset of homogeneous archetypes that represent groups of typologically identical buildings where information that would allow further differentiation is typically not available. This approach inevitably obscures the natural variability of occupant behavior and construction elements, but in turn reduces requirements for data acquisition and computational load.

The definition and use of building archetypes for urban-scale modeling have undergone a lot of work in recent years. In general, the literature describes the process of defining archetypes as consisting of three steps before simulation: (1) classification of build-

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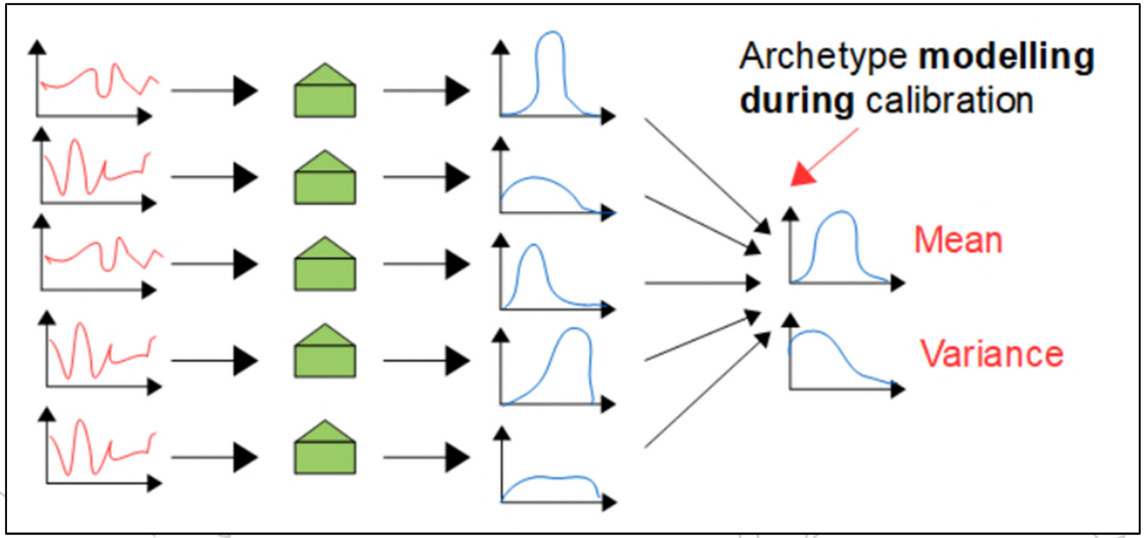
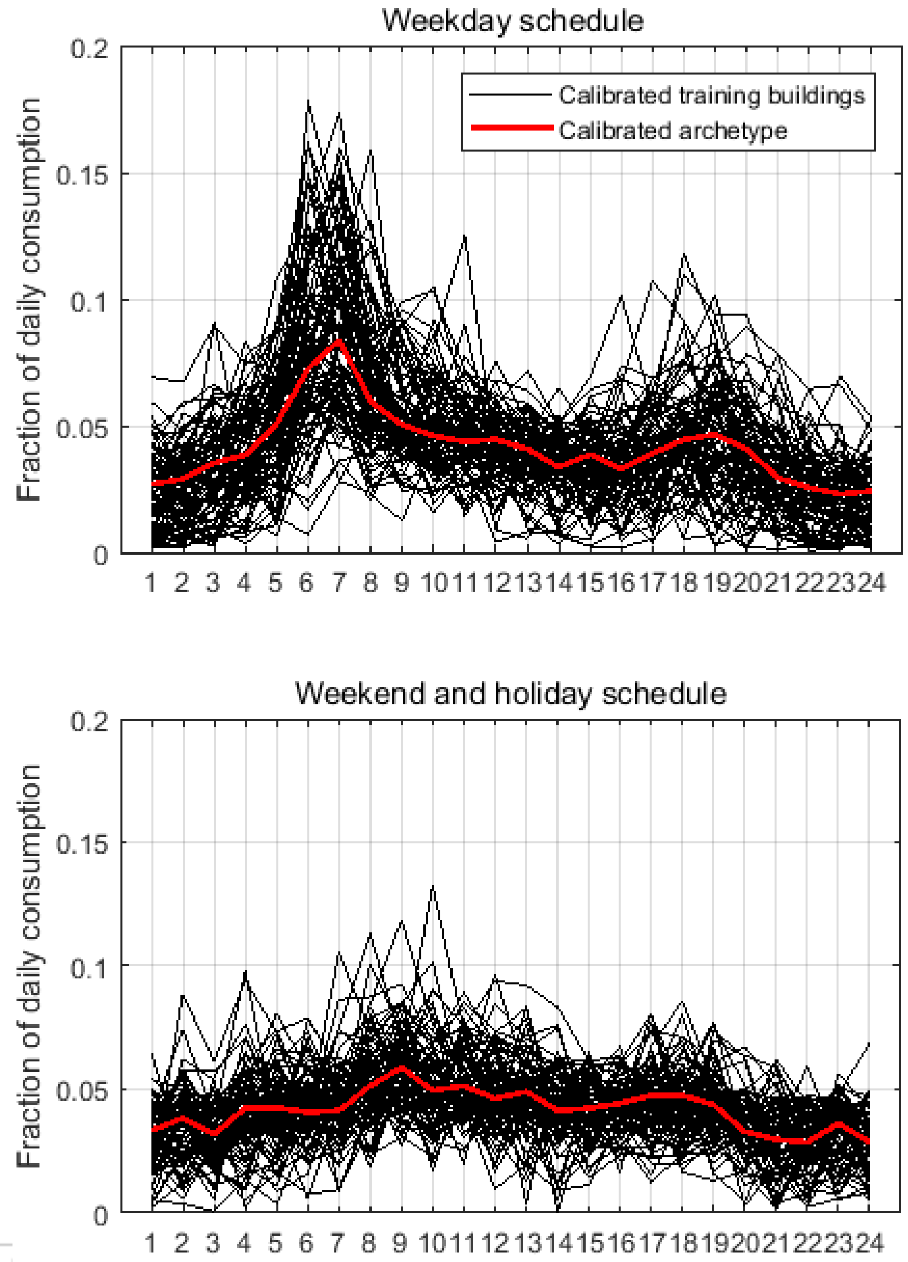
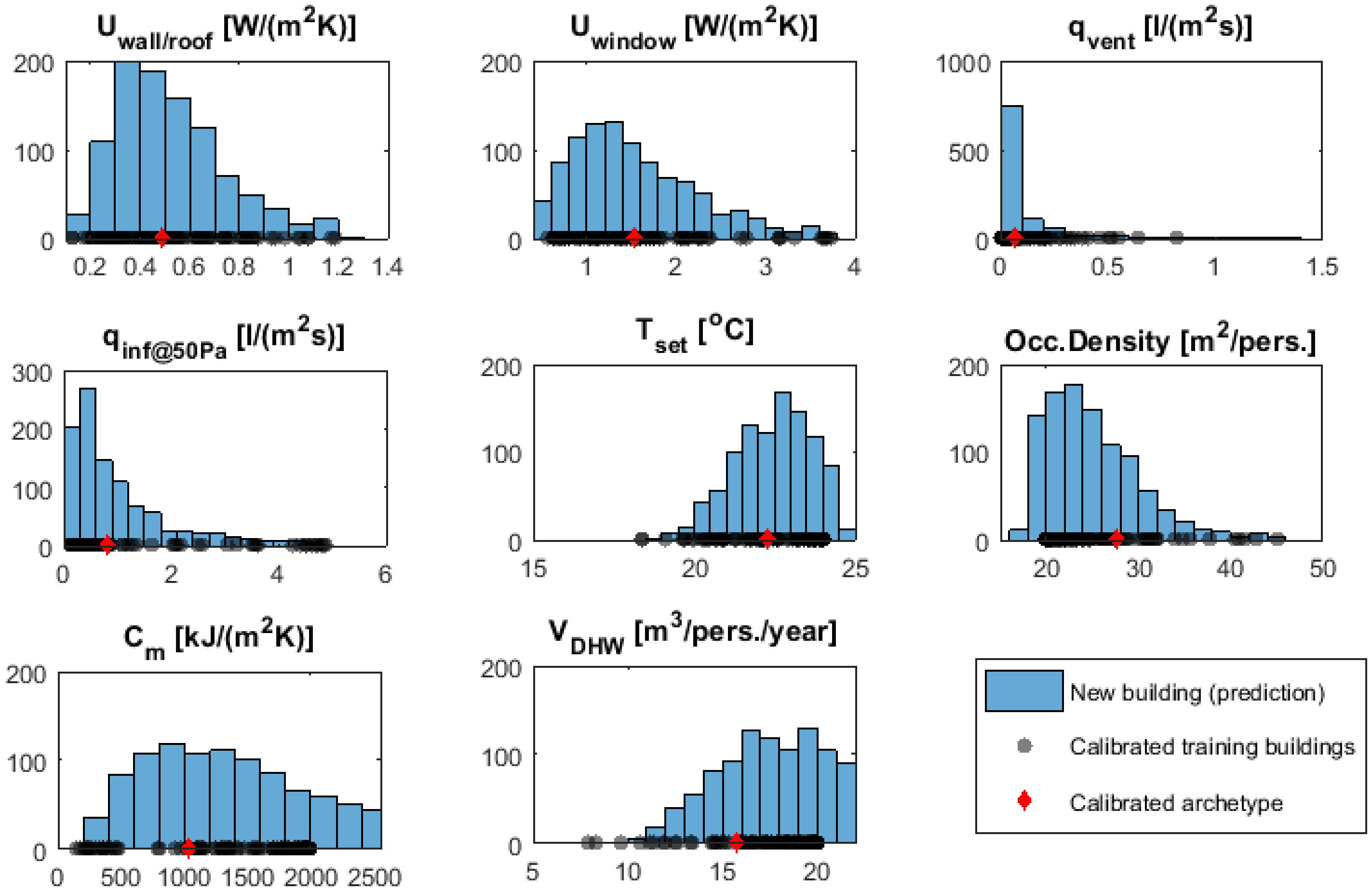


Resultater (1/3)



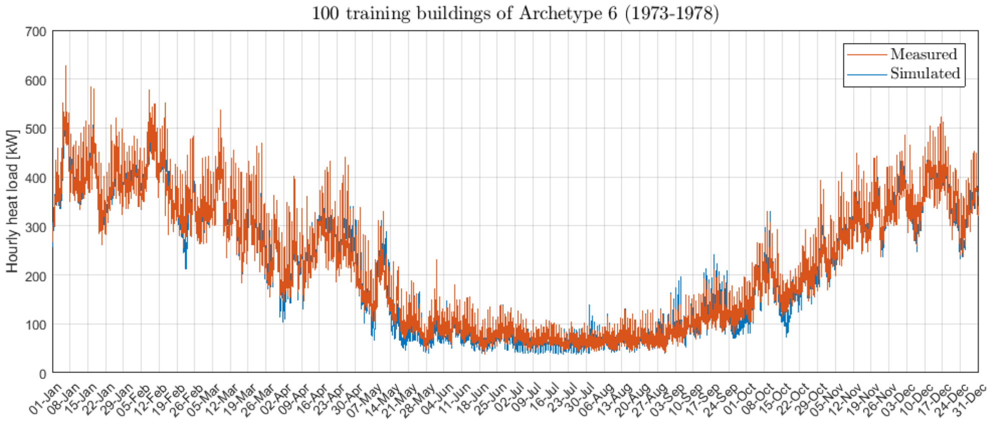


Resultater (2/3)

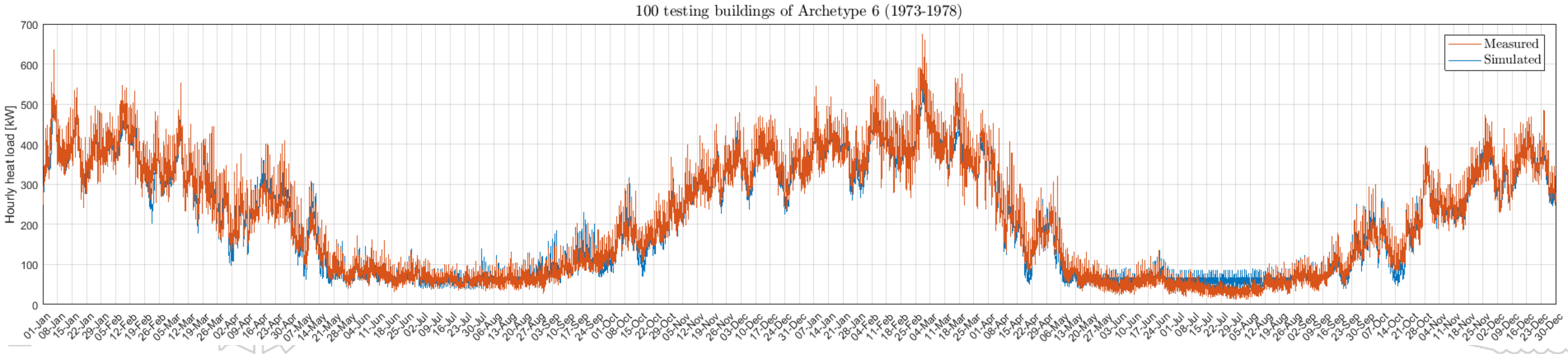
- Prædiktiv nøjagtighed for en af arketyperne (Arketype 6, 1973-1978).

- Alle arketyper har nogenlunde samme præcision i deres simuleringer.

100 arketype **træningsbygninger** kalibreret vha. 2017 data.
<u>Nøjagtighed:</u>
- Bias < 1%
- Timefejl < 10%

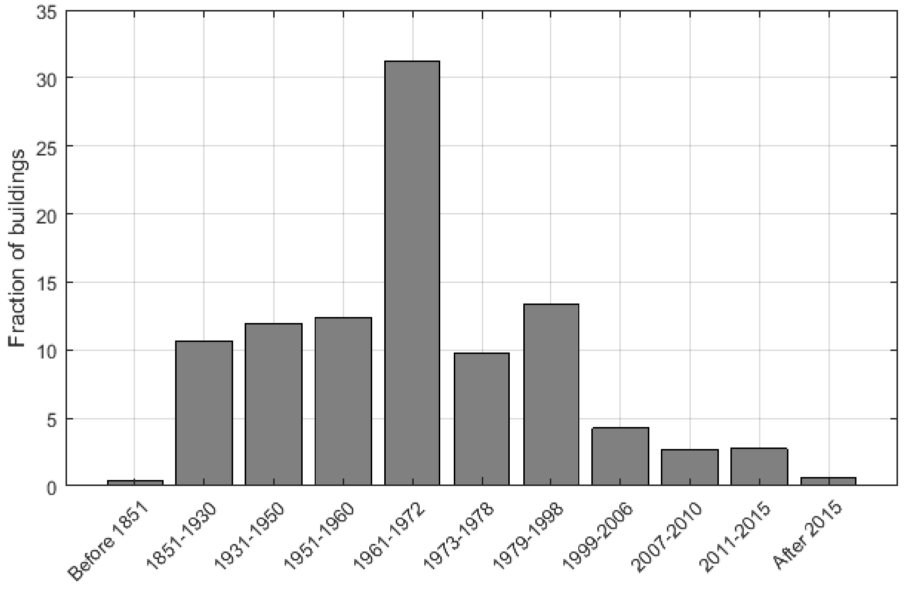


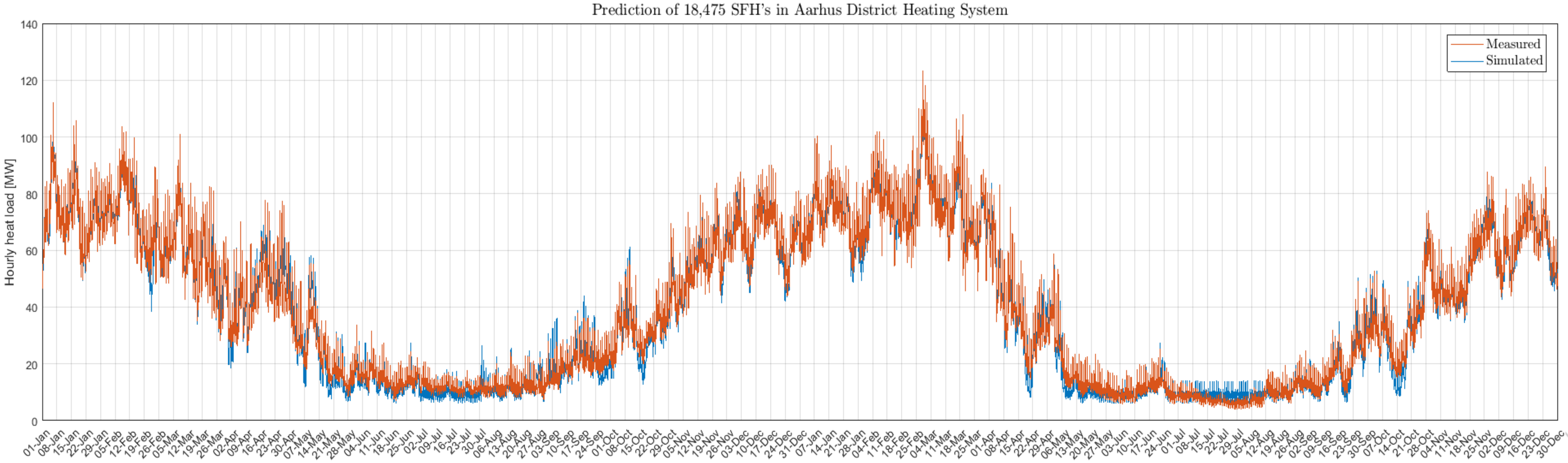
100 arketype **testbygninger** kalibreret vha. 2018 data.
<u>Nøjagtighed:</u>
- Bias < 2%
- Timefejl < 15%



Resultater (3/3)

- Byskala simulering af Aarhus.
- Validerings-data for 18.475 parcelhuse.
- Simuleringstid på laptop (100 stokastiske gentageler): Ca. 4 timer.
- Prædiktiv nøjagtighed:
  - Middel-bias: -0.3%.
  - Gennemsnitlig absolut timefejl: 11.8%.





Hvad kan vi bruge det til?

<u>Kortsigtede varmeprognoser:</u>

- Daglige og ugentlige prognoser af produktionsbehovet i et hvilket som helst geografisk område af netværket.

- Kun vejrprognoser og BBR data er nødvendige når først arketyperne er kalibreret.

<u>Strategisk energiplanlægning og analyse:</u>

- Dimensionering af fjernvarmenetværk i nye byområder eller omlægning af eksisterende rør ved byfortætning.

- Analyse af effekterne ved energirenovering af de forskellige arketyper.

- Analyse af fleksibilitetspotentialet (demand response) af de forskellige arketyper.

- ….

Analyse af renoveringspotentialet fra 2017 og frem til 2050

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Vejrdata fra 2017-2050

FN's klimafremskrivninger

- *Representative concentration pathways* (RCP's) er fremskrivninger af hvordan solstrålingsniveauet, og dermed klimaet, udvikler sig frem mod år 2100.
- FN's klimaplan arbejder med 4 forskellige RCP'er for hvordan klimaet udvikler sig.
- Her medtaget hhv. det mest optimistiske og det mest pessimistiske bud.

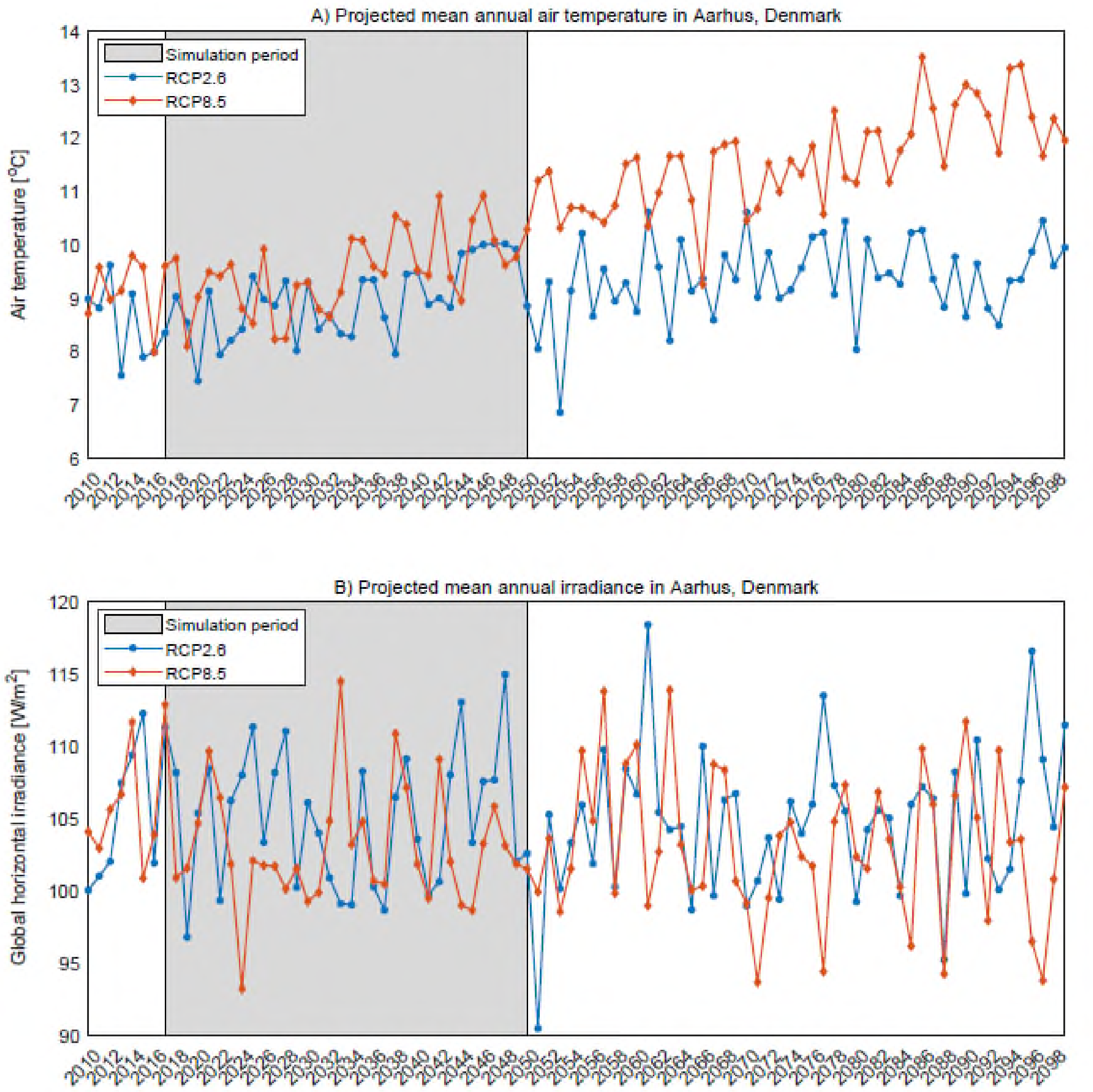

Figure 8.7. Projections of mean annual air temperature and global horizontal irradiance in Aarhus, Denmark, from 2010 up until 2100 using representative concentration pathways RCP2.6 and RCP8.5, respectively. Only the period shaded in grey (2017-2050) is used for simulation.

Renoveringsscenarier

Tre forskellige energirenoveringsscenarier:
- 0% pr. år (samme niveau som år 2017)
- 1% pr. år (nuværende gennemsnitlig rate i EU)
- 5% pr år (meget optimistisk scenarie)

Energirenovering:
- Hvert år sorteres bygningerne på baggrund af deres samlede varmetabskoefficient [W/(m^{2}K)] fra højest (dårligst) til lavest (bedst).

- De værste, fx 1%, af bygningerne udsættes for energirenovering hvert år.

Table 8.4. Replacement values for the three building elements when engaged in retrofit. Only if the current building element value exceeds the retrofit threshold value is it replaced with the new standard value.

Building element	Retrofit threshold	New standard
Ext. walls	U-value >0.5 [W/(m^{2}K)]	U-value = 0.5 [W/(m^{2}K)]
Roof	U-value >0.5 [W/(m^{2}K)]	U-value = 0.3 [W/(m^{2}K)]
Windows	U-value >2.5 [W/(m^{2}K)]	U-value = 1.5 [W/(m^{2}K)]

Prognosen

- Simuleringerne blev gentaget 200 gange pr. renoveringsscenarie for at udforske usikkerheden i bygningernes forudsagte parameter-værdier.

- Der er store variationer imellem de enkelte år fordi der er variationer i klimafremskrivningerne.

- Besparelsespotentialet i år 2050:
  - 30-45% hvis 5% af bygningerne renoveres pr. år.
  - 20-25% hvis 1% af bygningerne renoveres pr. år.

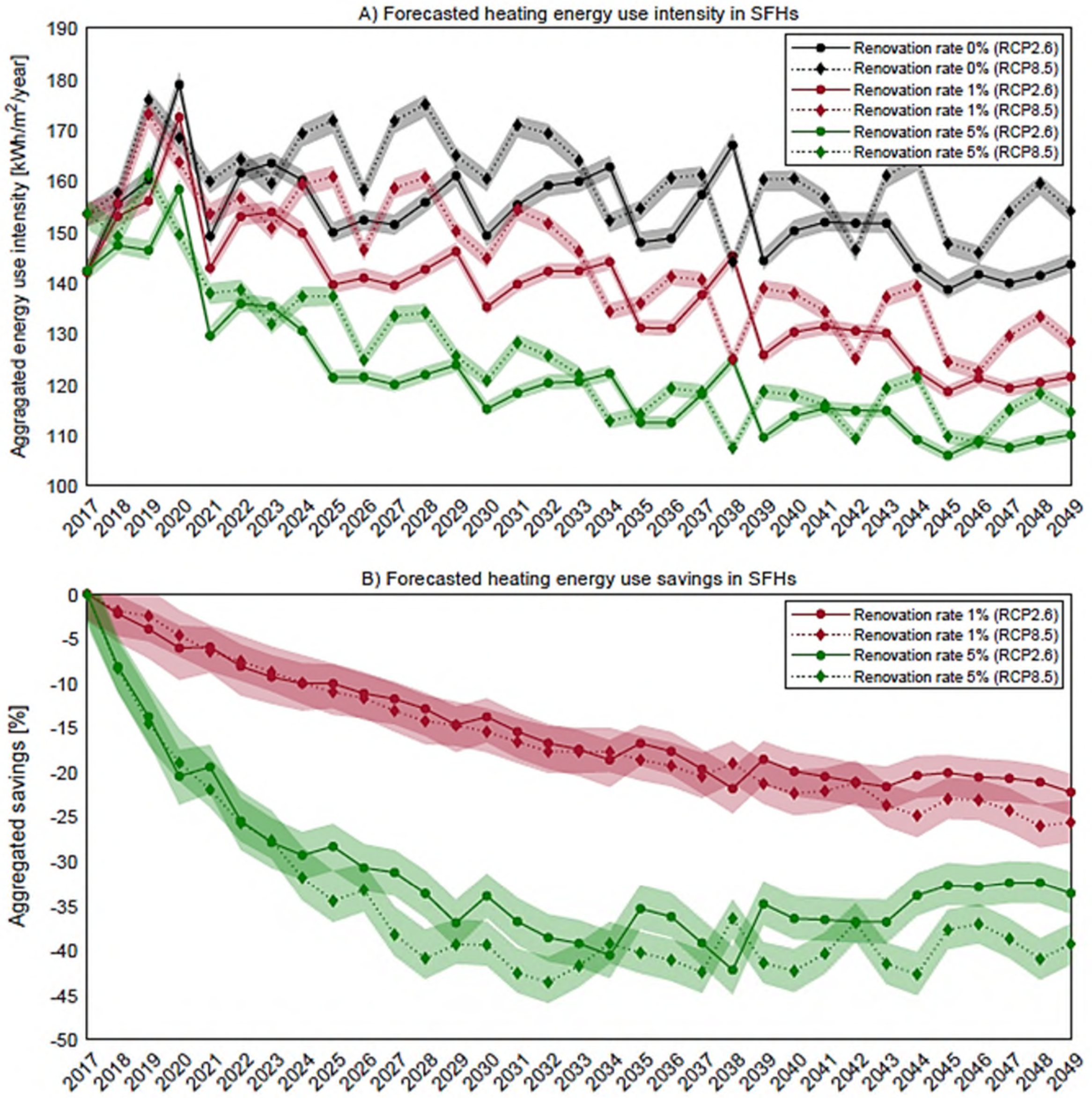

Figure 8.8. Forecasts of the aggregated energy use of 22,914 SFHs from 2017 up until 2050. A) Aggregated energy use intensity of the buildings for renovation rate scenario 0%, 1% and 5%, all simulated using both RCP-scenarios, respectively. Each of the trajectories constitute the mean of $N_\theta = 200$ chains of consecutive and interconnected simulations with the shaded bands visualizing the 95%-HPD of the simulations. B) Aggregated savings potential of a renovation rate scenario of 1% and 5%, respectively, relative to a 0% scenario (no renovation).

Opsamling

- Højtopløst data på bygningsniveau udgør en enorm kilde til ny viden om forbrugerne og hvordan deres forbrugsmønstre påvirker fjernvarmedriften.

- Data kan bruges til:
  - Direkte dimensioneringsgrundlag for nye rørledninger.
  - Forbedring af prognoseværktøjer og produktionsplanlægning.
  - Diagnosticering af dårligt indregulerede units (dårlig afkøling).
  - Analyse af fjernvarmens fremtidige udfordringer.
  - Og sikkert meget meget mere…

Varmepumpe på Aarhus Ø

- 14 MW havvands-varmeumpe
- 2 MW er ved at blive installeret i øjeblikket. Forventes i drift oktober 2019.
- Massiv dataopsamling skal forbedre styring og implementering af VP’en i den daglige drift!

Tak for i dag

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