Aalto University
School of Engineering

# Comparative analysis of different types of solar district heating systems for a community in Finnish conditions

*IBPSA-Nordic*
*Lund University, Sweden*
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# Agenda

- Background, issues & research questions

- Design and analysis of
  - Solar thermal energy system-I, II and III configrations (TRNSYS model)
    - Building models for solar community (TRNBuild model)

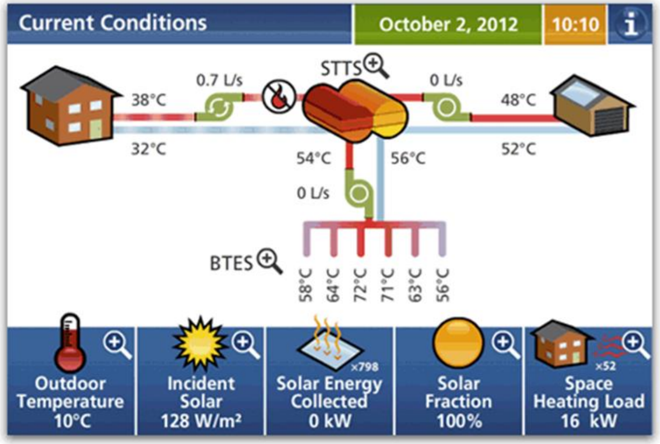
- Results
  - Exhaustive parametric search
  - Effect of different configurations on purchased energy and cost
  - Effect of design variables in different configurations.

# Background

- In **Finland, 80% of residential energy consumption** is used for **space heating and domestic hot water heating = *emissions***

- Numerous solar district heating and seasonal sensible thermal storage projects have been realized in Europe and North America.
  - Germany, Sweden, Denmark and Canada

- Two **solar community** concepts at a small scale had been build and tested in **Finland** in **Kerava (1980s) and Eko- Viikki (without seasonal storage).**




Size & Cost

https://www.dlsc.ca/

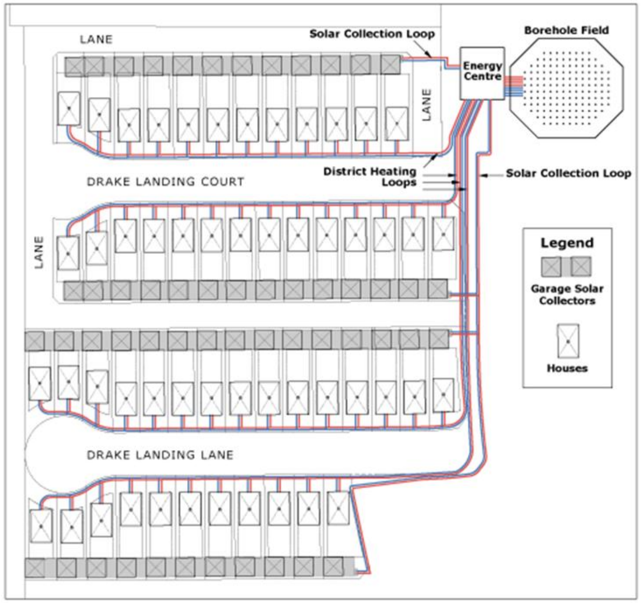
# Background and challenges : Finland

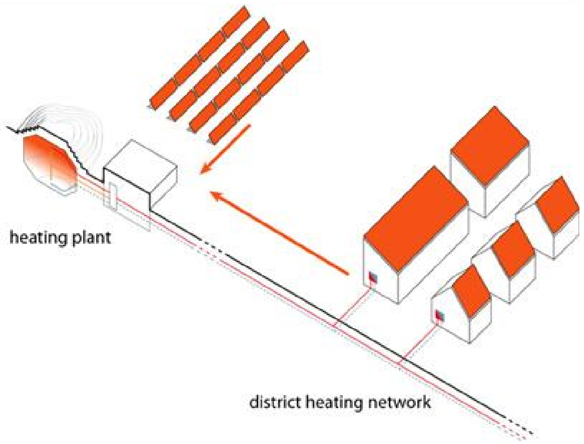
- At high latitudes there are four major challenges:
  - the weather is extremely cold during winters
  - the annual mismatch between irradiation and demand
  - the resulting energy costs are not yet competitive
  - the losses from the seasonal storage are high due to ground conditions

- Seasonal storage is essential in Nordic conditions. There are several sensible storage:
  - hotwater TES (HWTES)
  - aquifer TES (ATES)
  - gravel water TES(GWTES)
  - **borehole TES (BTES)**

- BTES is considered because:
  - simplicity of its storage
  - adaptability (through drilling additional boreholes)
  - flexibility in terms of location
  - its cost effectiveness
  - In Finland the rock conductivity is 3.24 ± 1.00 W/m.K

- We found that, solar district heating is influenced by
  - Climate of the location
  - Control algorithm

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# Research Questions and motivation

- **Influence of the configuration & components on the system performance**
  - *Does system configuration has any effect on performance? Behavior? And how much?*
  - *Does each component in each configuration has effect on the performance? And how much?*

- **Influence of the building construction on the system performance**
  - *Which building design variables have significant effect on the building performance?*
  - *Does building configuration has any effect on system performance ? And how much?*

**Motivation: Maximize the use of the solar energy by 90% for the community sized heating energy demand in cold climate.**



http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/files/pdf/2012%20R2000%20Standard%20EN.pdf
http://www.sciencedirect.com/science/article/pii/S0960148115002189
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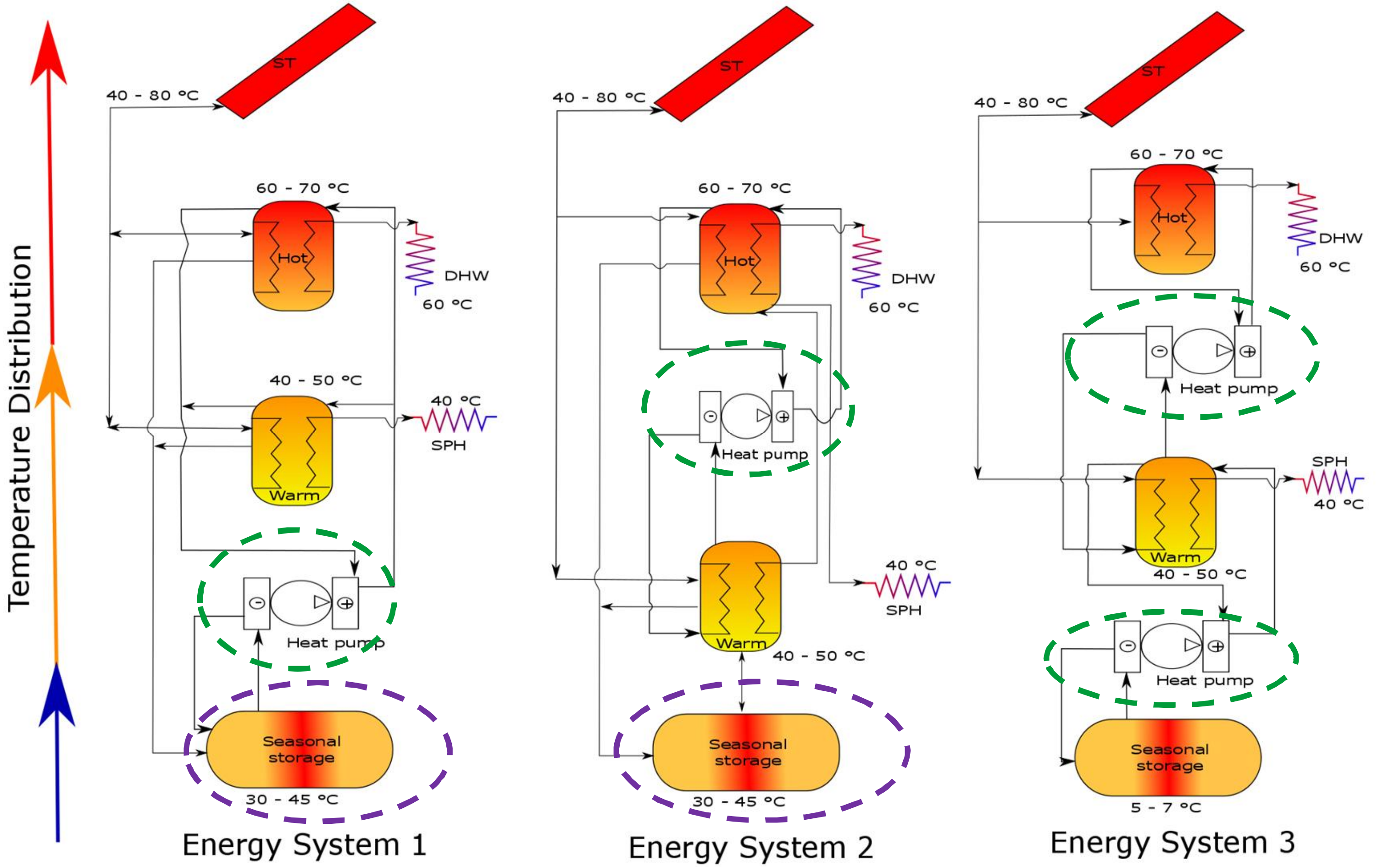
## Energy system simulation-TRNSYS

# Energy System- I, II and III




Larger depth of BTES in system-III



Rehman, Hirvonen, Sirén 2017: A long-term performance analysis of three different configurations for community-sized solar heating systems in high latitudes, Renewable Energy 113:479–493.
http://www.sciencedirect.com/science/article/pii/S0960148117305189

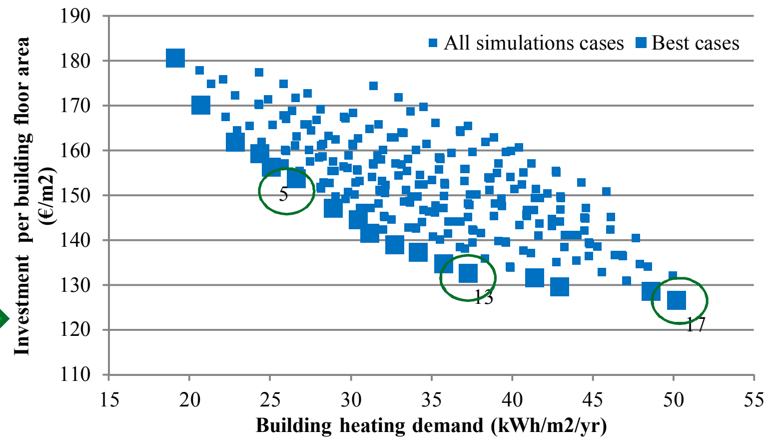
# TRNBUILD : Building Demand - Detached Homes

## Input Variables:

100 houses: 100 m$^2$ floor area each

- Walls insulation thickness
- Roof insulation thickness
- Floor insulation thickenss
- Windows U- Value
- Heat recovery efficiency

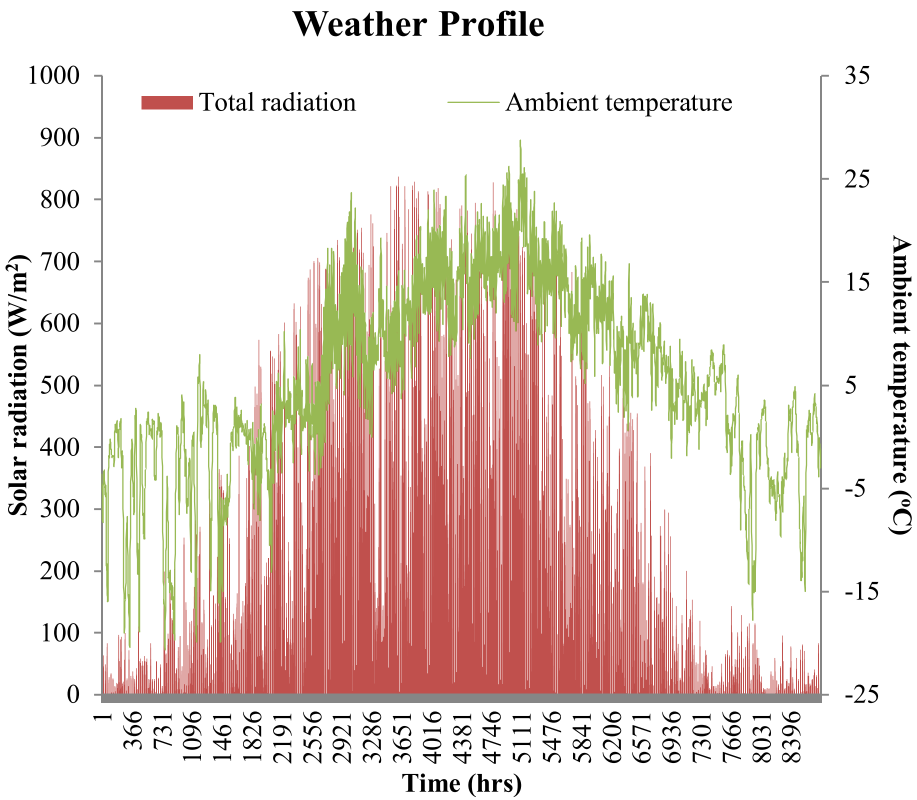
## Output:

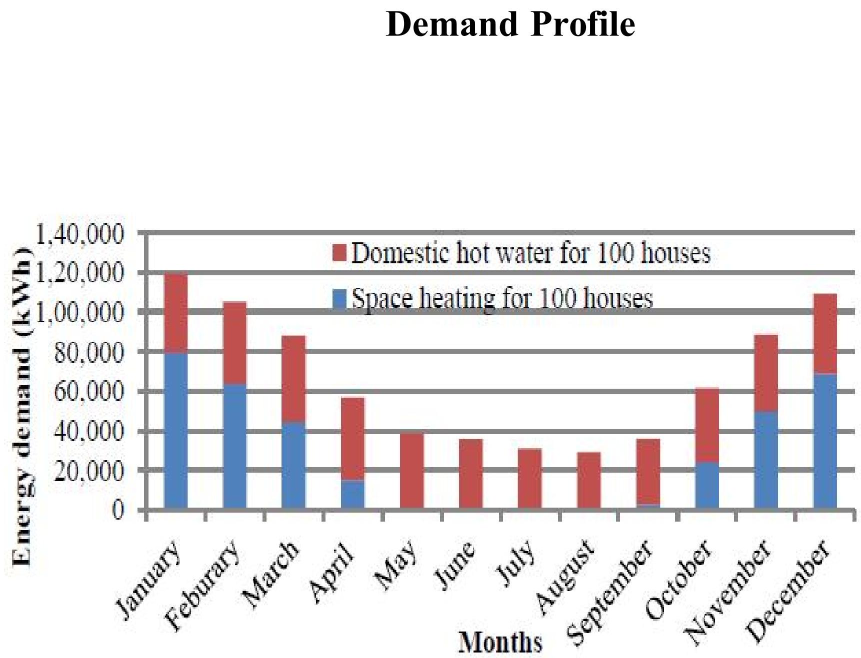



Annual heating demand and investment cost

- Invest,
  - Higher in **heat recovery efficiency**
  - Low in **floor insulation**
  - Windows

# Demand & Weather Profile: 60 °N, Finland

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# Simulation Cases

## Input Variables:

Based on Drake landing as reference case.

| Design variable | Range/value | Prices | Options |
|---|---|---|---|
| ST Area ($m^2$) | 2000, 4000, 8000 | 365 €/$m^2$ , 347 €/$m^2$ , 314 €/$m^2$ | 3 |
| Warm tank volume ($m^3$) | 120,240,480 | 500 €/$m^3$ | 3 |
| Hot tank volume ($m^3$) | 120,240,480 | 500 €/$m^3$ | 3 |
| BTES volume($m^3$) | 33650, 67300, 134600 | 17.19 €/$m^3$ | 3 |
| PV area($m^2$) | 1000, 2000, 4000 | 230.7 €/$m^2$ | 3 |
| Building configuration | Type 1: heating demand= 25kWh/$m^2$/yr<br>Type 2: heating demand= 37kWh/$m^2$/yr<br>Type 3: heating demand= 50kWh/$m^2$/yr | 15 628 €/building<br>13 260 €/building<br>12 655 €/building | 3 |

- *Solar system configurations – <u>Energy system -I, Energy system -II, Energy system -III</u>*
- For all three systems **3x729=2187**

## Output:

- **Renewable energy fraction, Annual purchased energy and investments cost**

# Energy System-I, II & III Performance

**Energy System I-** heat pump is between the short terms tanks

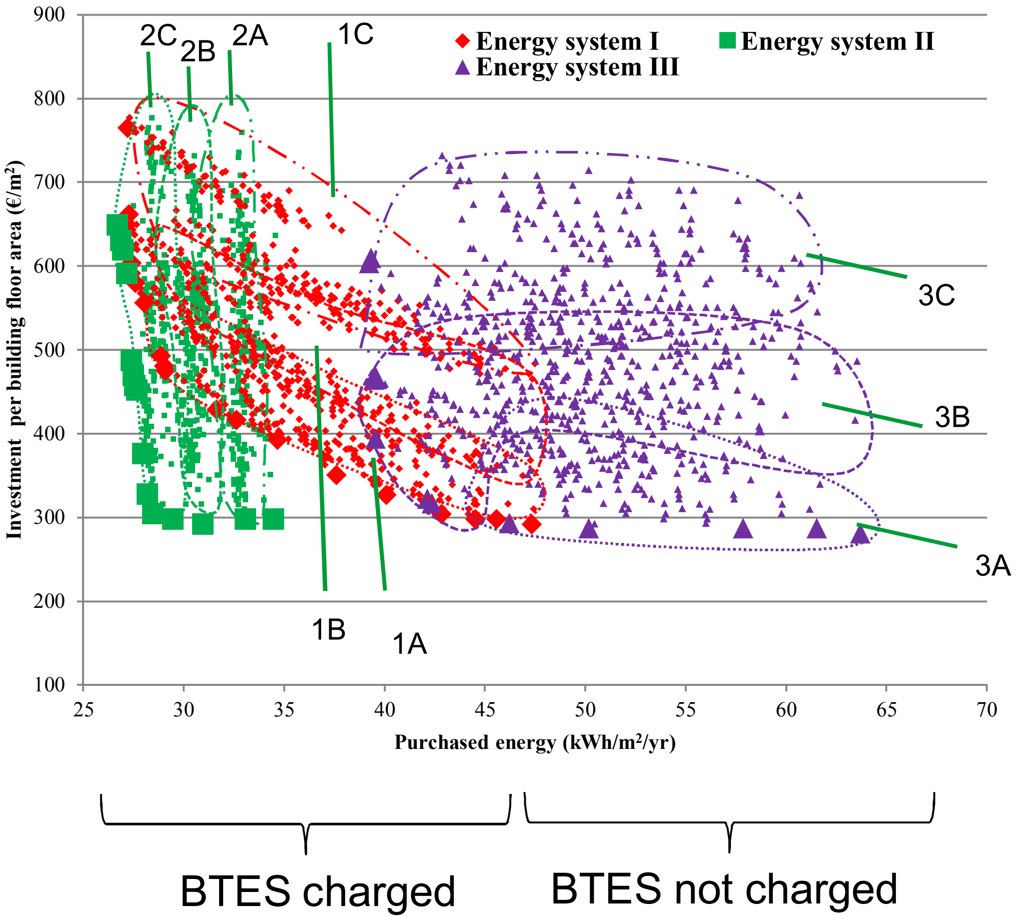
- 1A: the majority of the system configuration contained seasonal storage of a lesser size
- 1B: the majority of the system configuration contained seasonal storage of a medium size
- 1C: the majority of the system configuration contained seasonal storage of a larger size

**Energy System II-** heat pump is between BTES & short terms tanks

- 2A: Majority of the system configuration contained seasonal storage of a smaller size
- 2B: Majority of the system configuration contained seasonal storage of medium size
- 2C: Majority of the system configuration contained seasonal storage of a larger size

**Energy System III-** Cascade heat pump and BTES not charged

- 3A: Majority of the system configuration contained seasonal storage of a small size.
- 3B: Majority of the system configuration contained seasonal storage of a medium size
- 3C: Majority of the system configuration contained seasonal storage of a large size.







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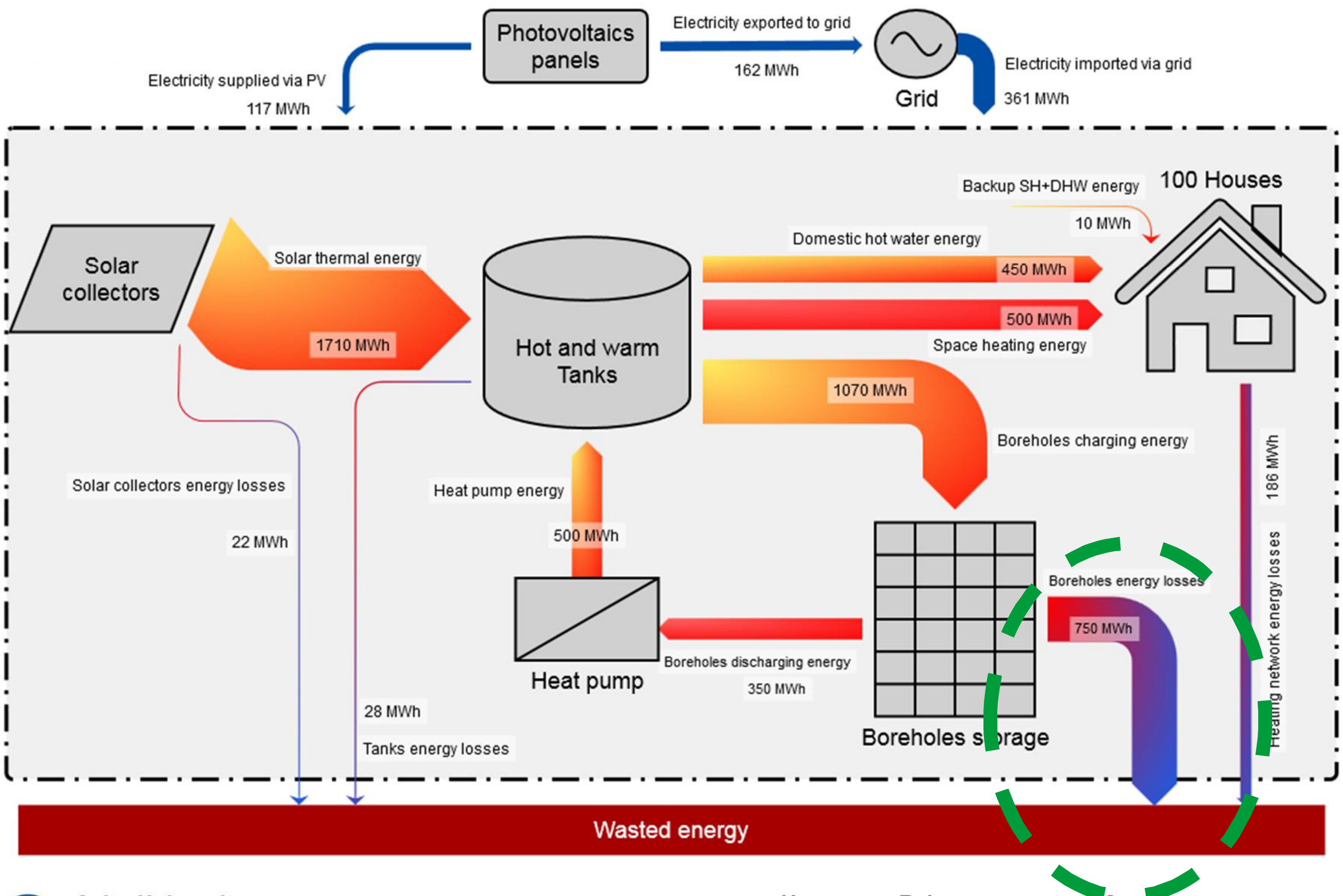
# Sankey flow – Energy System II



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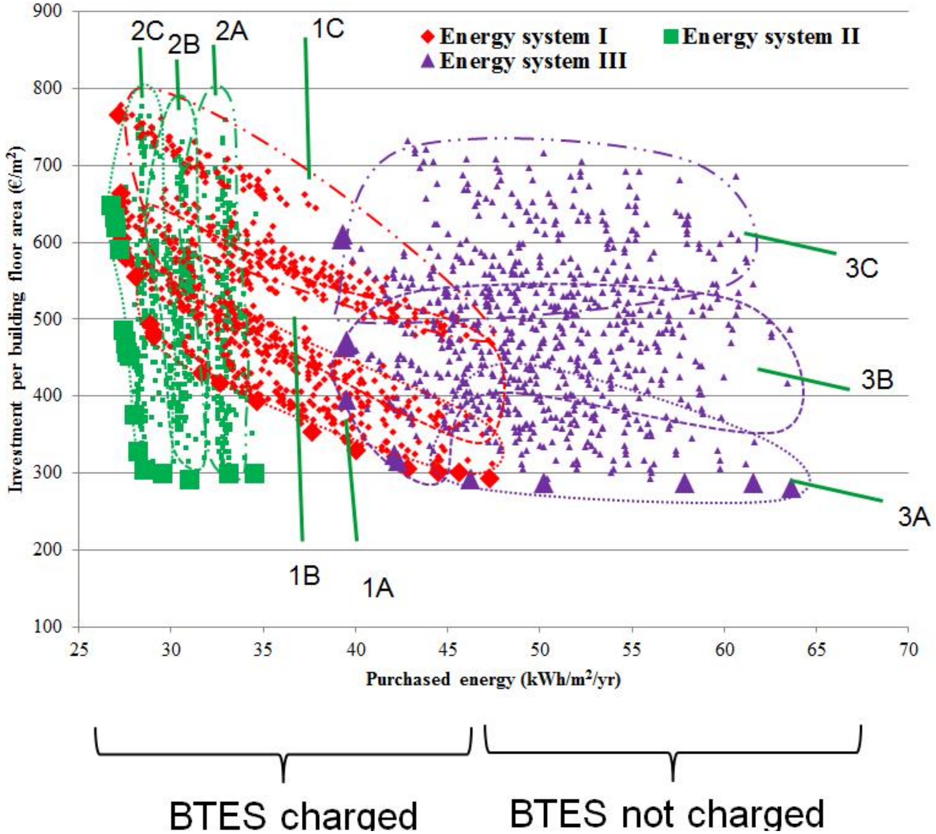
# Energy System-I, II & III Performance

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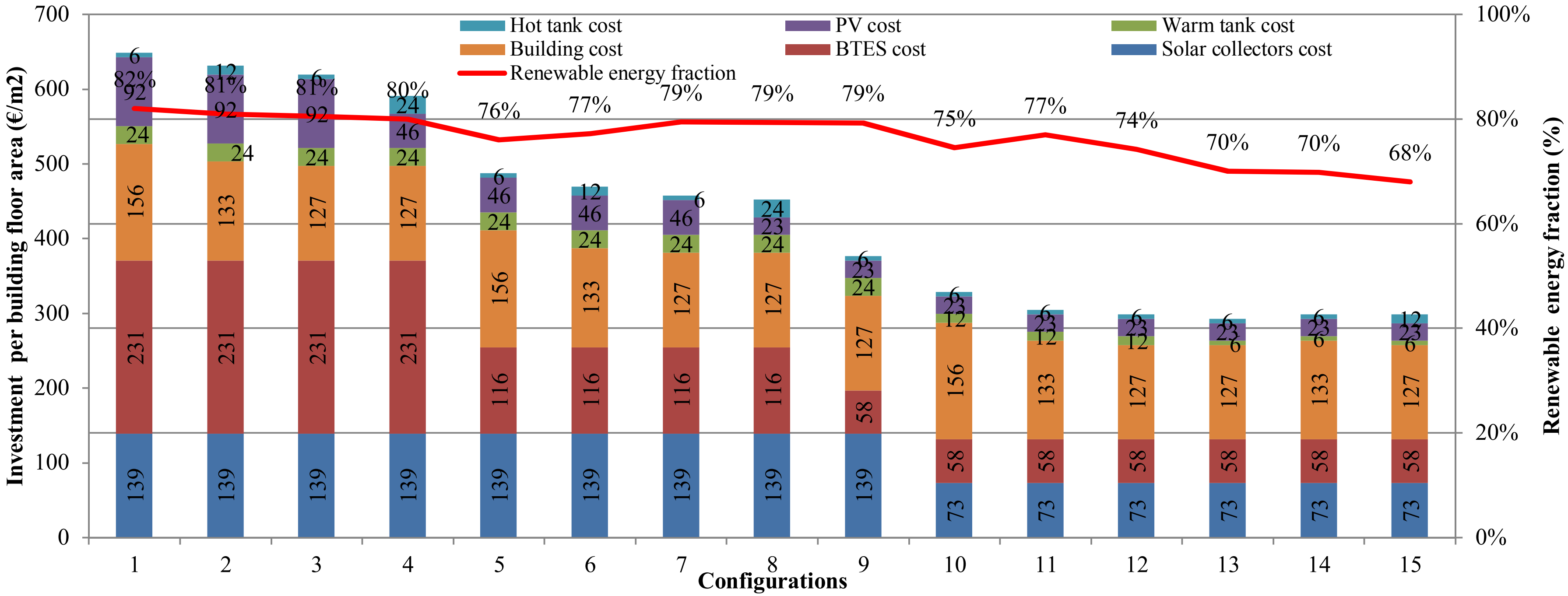
# Energy System-II, BTES charged: Costs Results




- Most cases have **large to medium sized seasonal storage (BTES)**
- **Medium and small solar thermal area** performed best in all cases
- Buildings demand changed from **25 kWh/m²/yr to 50 kWh/m²/yr** (left to right)
- Renewable energy fraction **82 % - 68 %**

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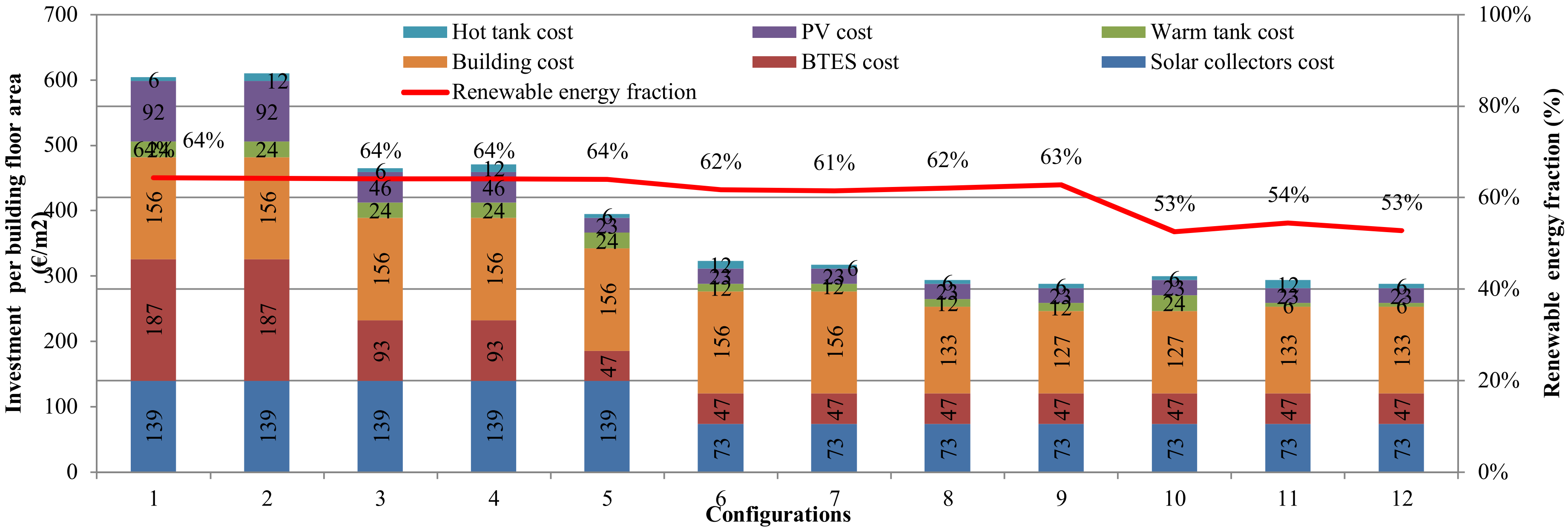
# Energy System-III, BTES not charged: Costs Results




- Most cases have **medium to small sized seasonal storage (BTES)**, however **large volume** improved the long term performance of the system (natural charging).
- Buildings demand changed from **25 kWh/m²/yr to 50 kWh/m²/yr** (left to right)
- Renewable energy fraction **64 % - 53%**

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# Conclusions

- **Improved performance when heat pump is between the short terms tanks (hot and warm tank)**~ System II and **not between the BTES and short term tanks** ~ System I, in both cases seasonal storage was charged

- **Storing solar energy in the ground increases the performance of the system** by increasing the renewable energy fraction from around **53%** (system III- with no BTES charging ) to **76~82%** (systems I & II- with BTES charging)
  - Larger depth of BTES is required in energy system III to balance natural charging of the BTES.

- **Losses through the BTES (seasonal storage) is significant in Finnish ground conditions**.

- **Large solar thermal collectors area** had minimal advantage in terms of reducing the annual electricity demand for heating.

- Buildings with heating demand of **25 kWh/m$^2$/yr** were proposed **in high performance cases** and **50 kWh/m$^2$/yr** in **least performance cases**, this resulted in **higher to lowest investments respectively**.

Thank you!

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