3RD INTERNATIONAL CONFERENCE ON

SMART ENERGY SYSTEMS AND
4TH GENERATION DISTRICT HEATING

COPENHAGEN, 12–13 SEPTEMBER 2017

Balancing Demand and Supply: Linking Neighborhood-level Building Load Calculations with Detailed District Energy Network Analysis Models

Towards Planning and Integrated Design of Urban Energy Networks

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Polytechnique Montréal

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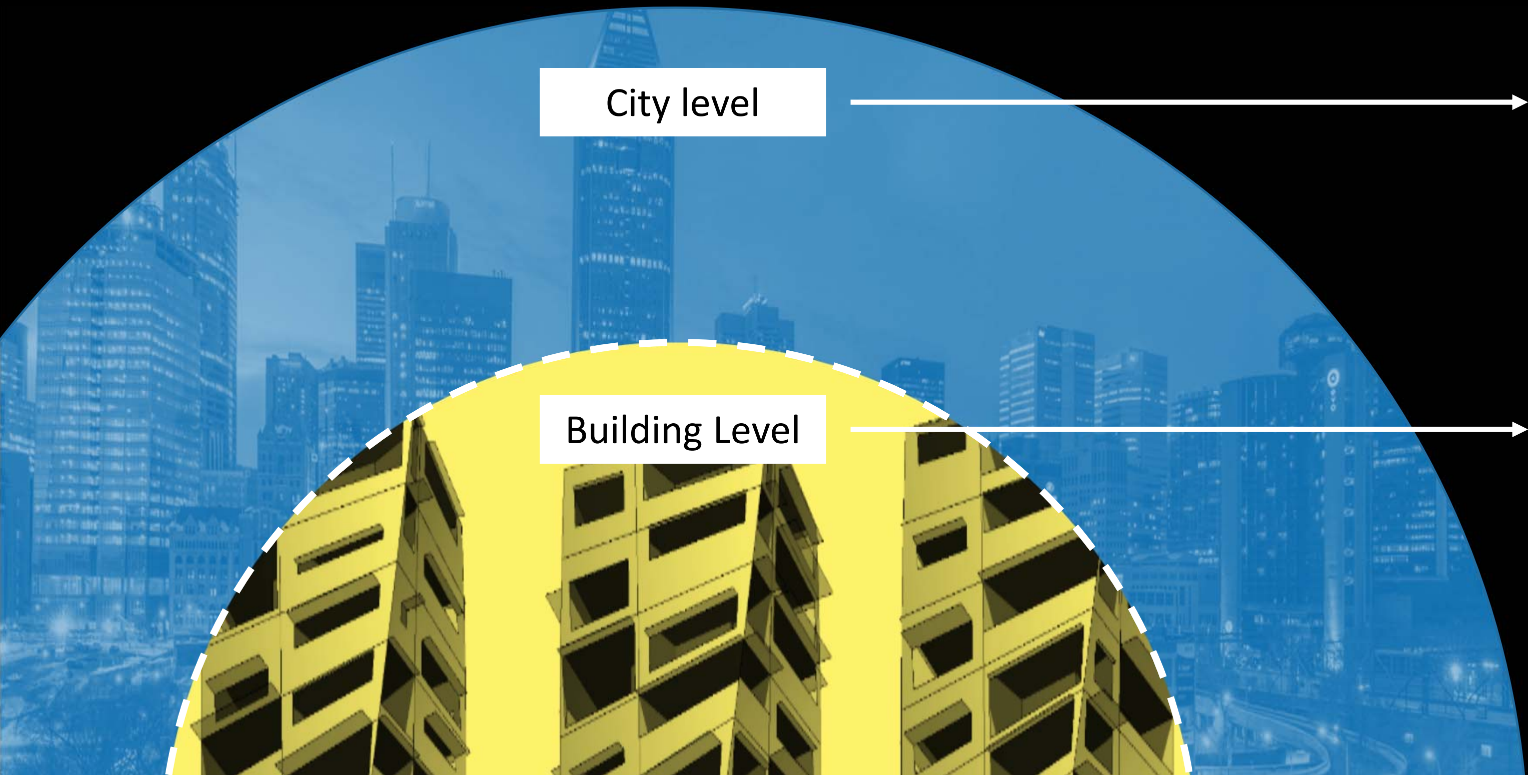
Prof. Christoph Reinhart
Massachusetts Institute of Technology

SDLAB

POLYTECHNIQUE MONTRÉAL

Context

In Architecture practices,
Shift towards "data-driven" design for buildings. . .



Urban Energy Building Modeling
- Can design intent at the urban level have a positive impact on district energy ?

Building Energy Modeling
- Sefaira
- Autodesk GreenBuildingStudio
- Energy Analysis for Dynamo

The problem

The current design strategy

Architectural
Programming

Engineering

Construction

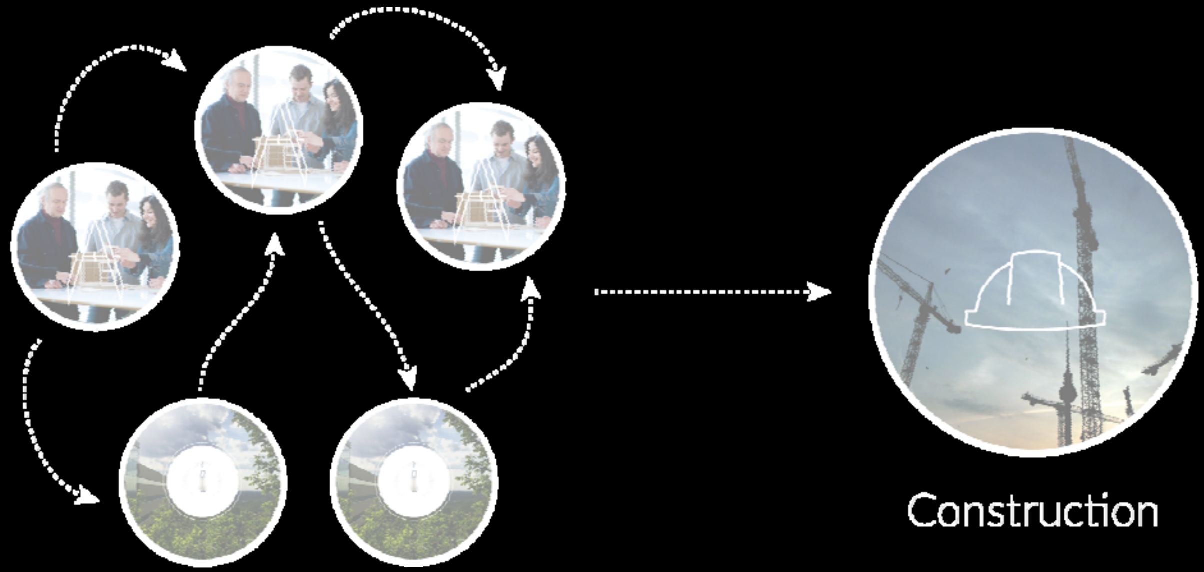
Master Planning:
Architectural programming
Massing
Zoning
Building design

Civil
Mechanical
Energy supply schemes

From plans to finished product

Solution

Solution for a better workflow:
Develop tools that empower Architects & Engineers to tackle energy supply earlier & together



Integrated design process

Requirements

- Integrate the tool into a platform familiar with designers
- Quickly assess building energy demand at the city level (when no measured data is available)
- Provide a way to define a distribution network configuration
- Allow a quick transition between a typical highly iterative process (architectural programming) and a more precise and reliable design process (system design)

Software base
Geometry & urban context

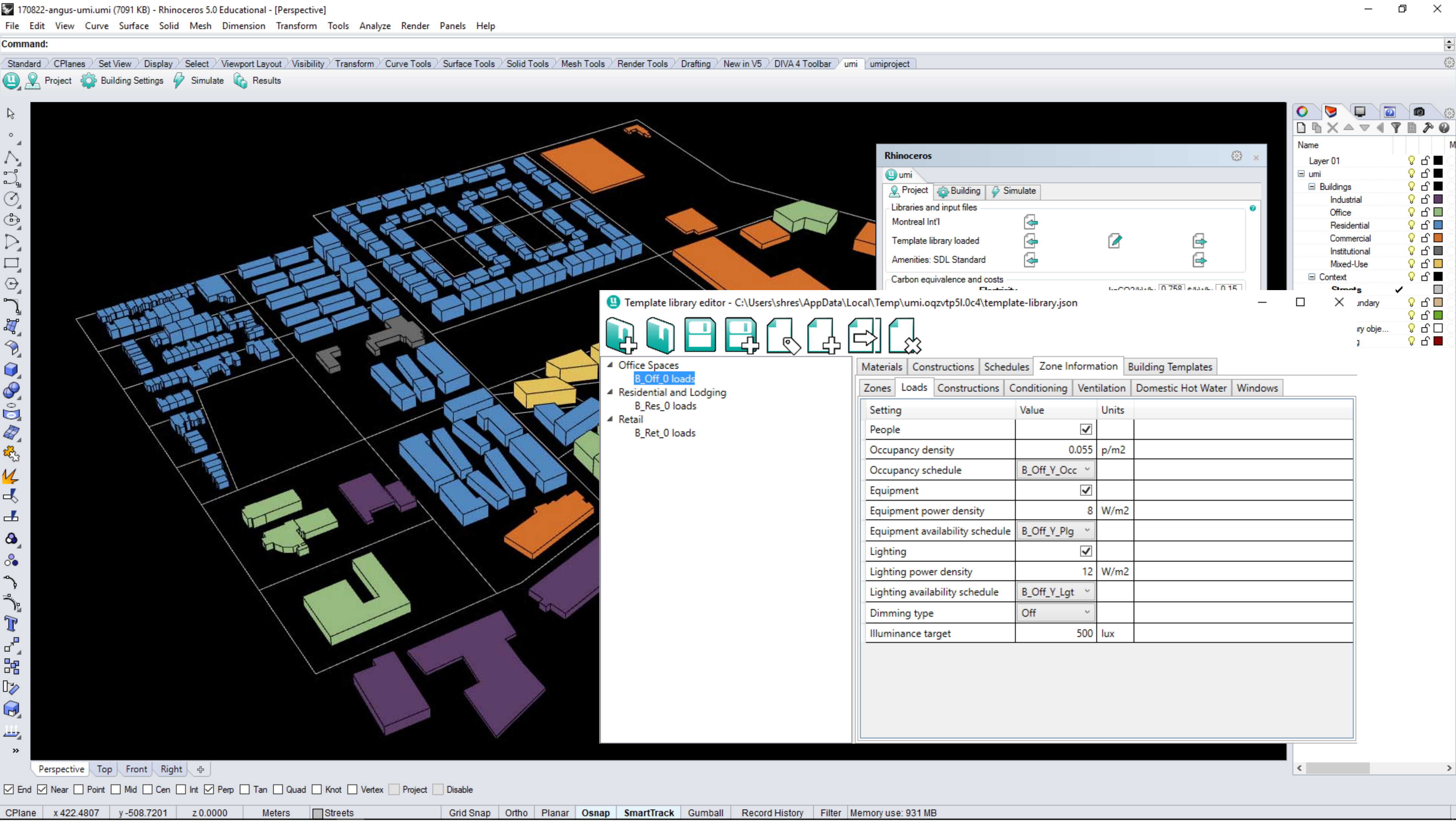
Rhinoceros

Urban Modeling Interface
Building Archetypes, Operational Energy, and more...

umi

Dynamic simulation engine
Distribution network
RES & Storage models
Control strategies

TRNSYS


170822-angus-umi.umi (7091 KB) - Rhinoceros 5.0 Educational - [Perspective]
File Edit View Curve Surface Solid Mesh Dimension Transform Tools Analyze Render Panels Help
Command:
Standard CPlanes Set View Display Select Viewport Layout Visibility Transform Curve Tools Surface Tools Solid Tools Mesh Tools Render Tools Drafting New in V5 DIVA 4 Toolbar umi umiproject
Project Building Settings Simulate Results
Rhinoceros
umi
Project Building Simulate
Libraries and input files
Montreal Int'l
Template library loaded
Amenities: SDL Standard
Carbon equivalence and costs
Template library editor - C:\Users\shres\AppData\Local\Temp\umi.oqzvtp5l.0c4\template-library.json
Office Spaces
B_Off_0 loads
Residential and Lodging
B_Res_0 loads
Retail
B_Ret_0 loads
Materials Constructions Schedules Zone Information Building Templates
Zones Loads Constructions Conditioning Ventilation Domestic Hot Water Windows
Setting Value Units
People
Occupancy density 0.055 p/m2
Occupancy schedule B_Off_Y_Occ
Equipment
Equipment power density 8 W/m2
Equipment availability schedule B_Off_Y_Plg
Lighting
Lighting power density 12 W/m2
Lighting availability schedule B_Off_Y_Lgt
Dimming type Off
Illuminance target 500 lux
Name
Layer 01
umi
Buildings
Industrial
Office
Residential
Commercial
Institutional
Mixed-Use
Context
Perspective Top Front Right
End Near Point Mid Cen Int Perp Tan Quad Knot Vertex Project Disable
CPlane x 422.4807 y -508.7201 z 0.0000 Meters Streets Grid Snap Ortho Planar Osnap SmartTrack Gumball Record History Filter Memory use: 931 MB

Typical workflow

1. Quantify the energy demand

Understanding the various energy demands of the project

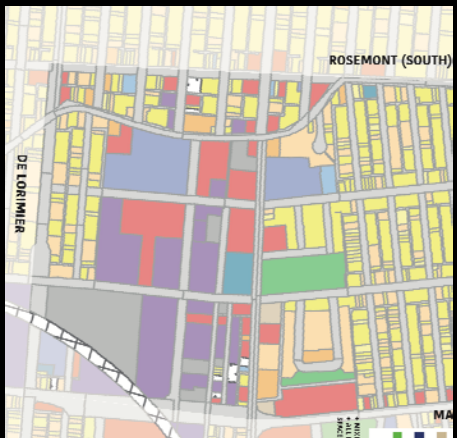
Typical Workflow Using the Tool
1. Quantify the energy demand
for large scale projects

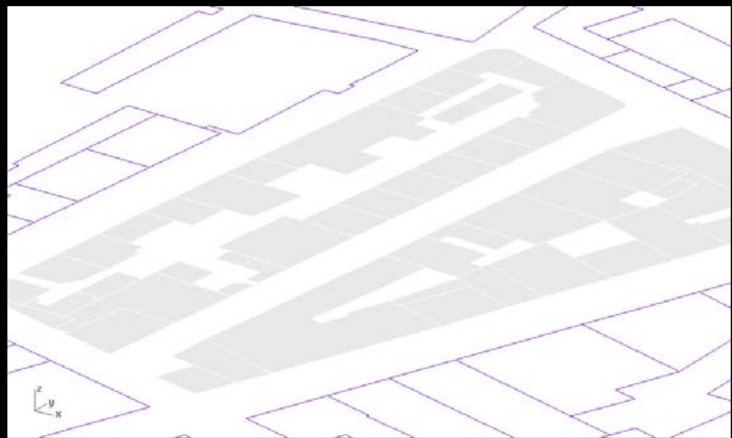
1. Centralize Data GIS
- Zoning
- Bldg footprint
- Construction year

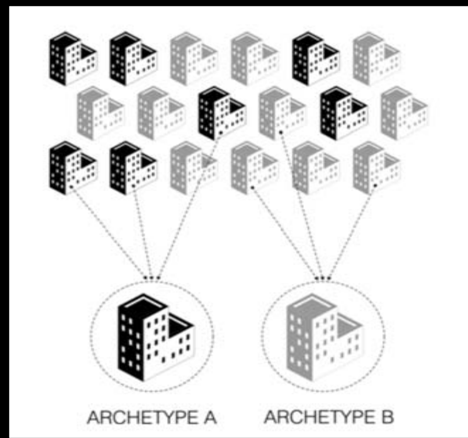
2. 2.5D geometry extraction

3. Assign building archetypes

4. Energy Simulation
- UMI
- EnergyPlus
- TRNSYS







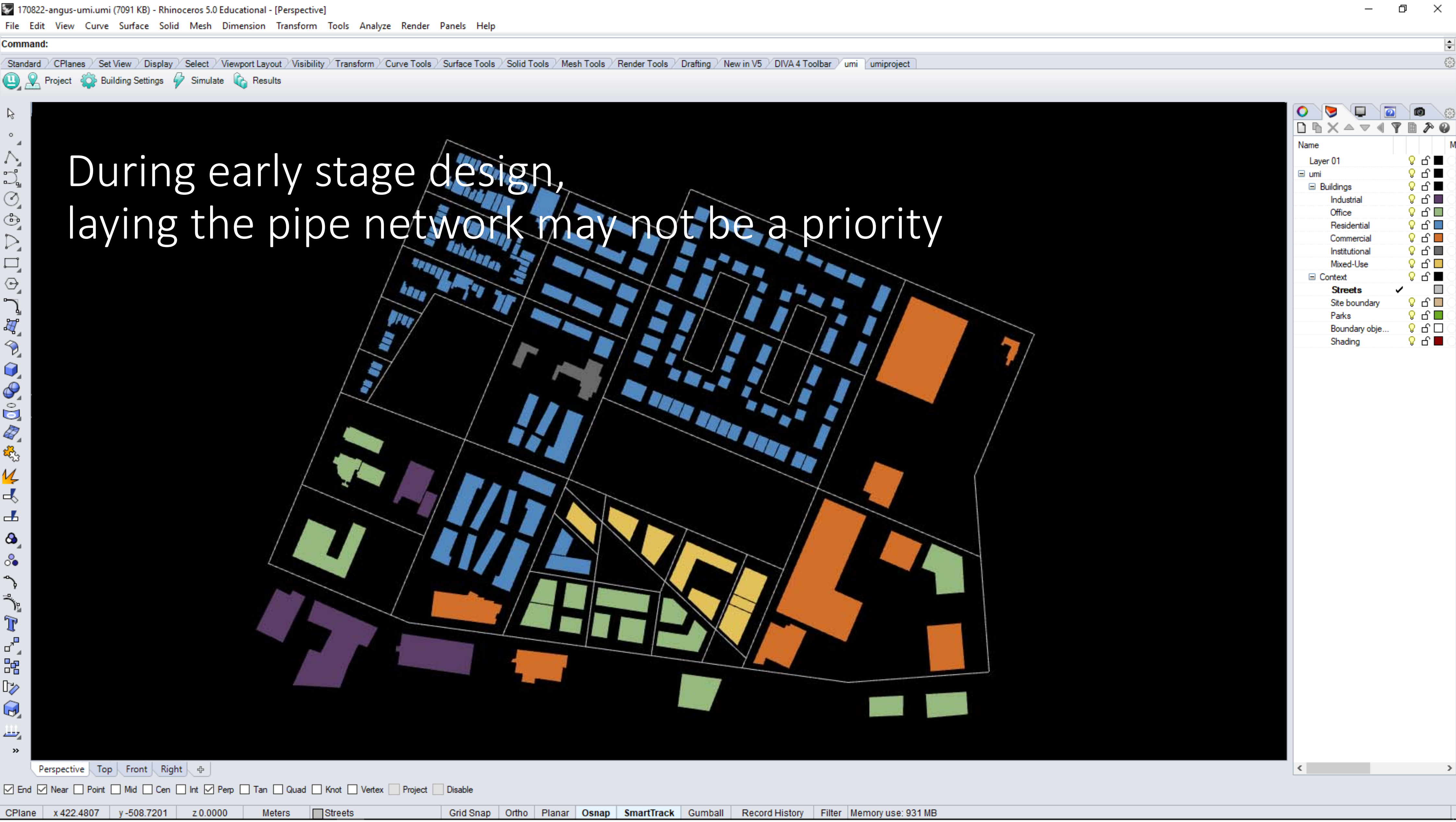
Typical workflow

2. Define the distribution network

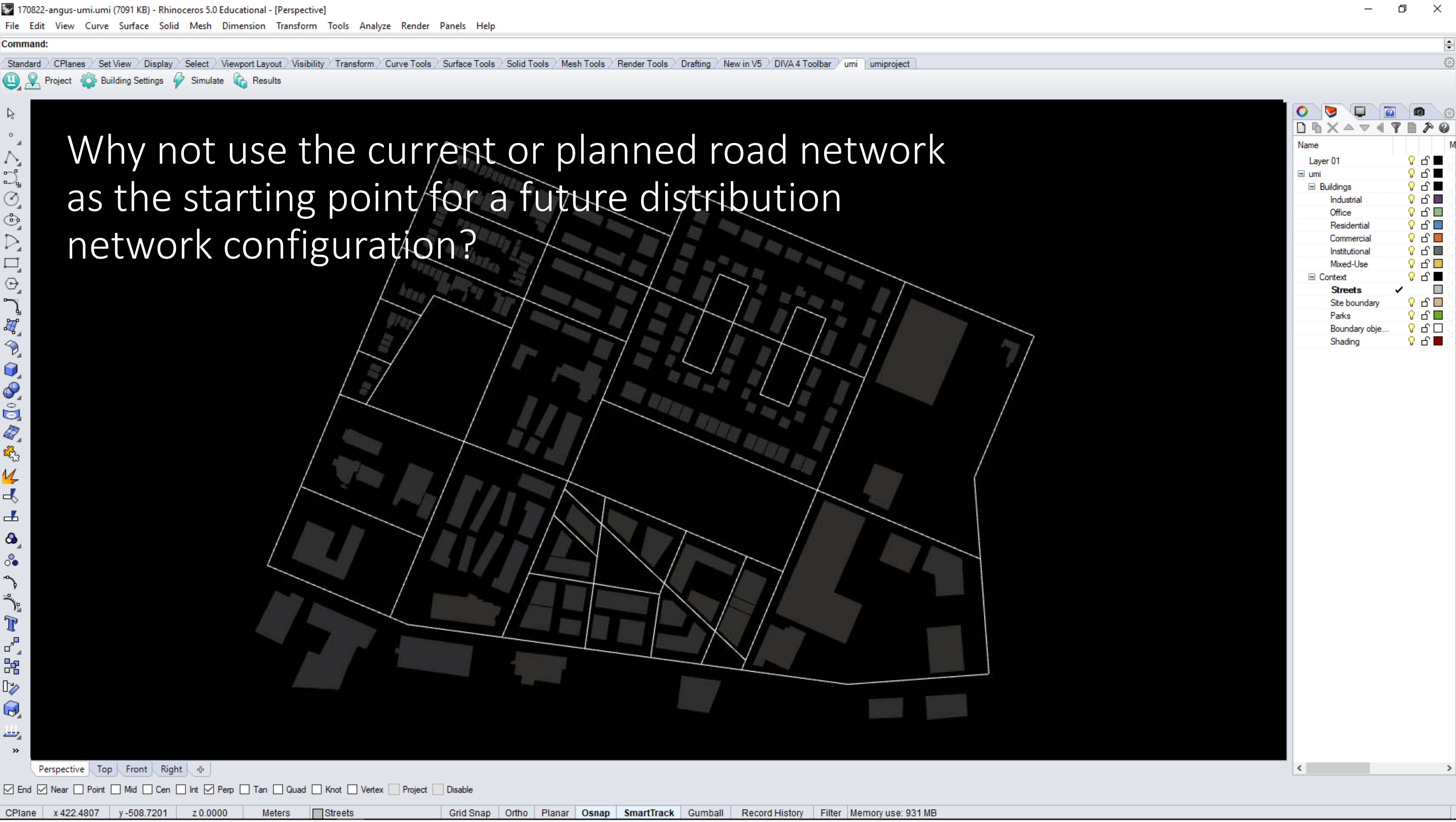
What's the total length of the network?

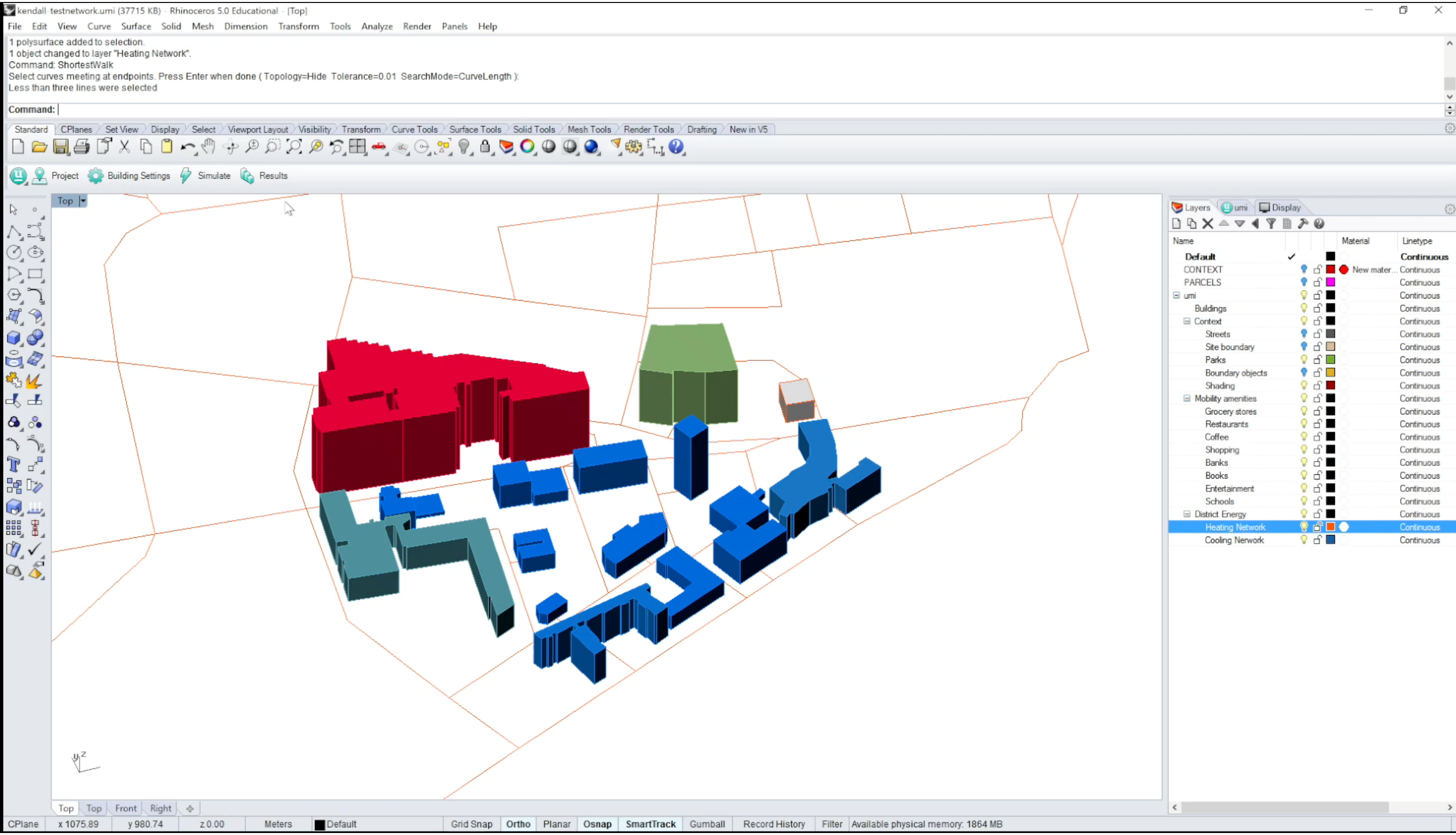
Should all the buildings be connected?

During early stage design,
laying the pipe network may not be a priority



Why not use the current or planned road network as the starting point for a future distribution network configuration?

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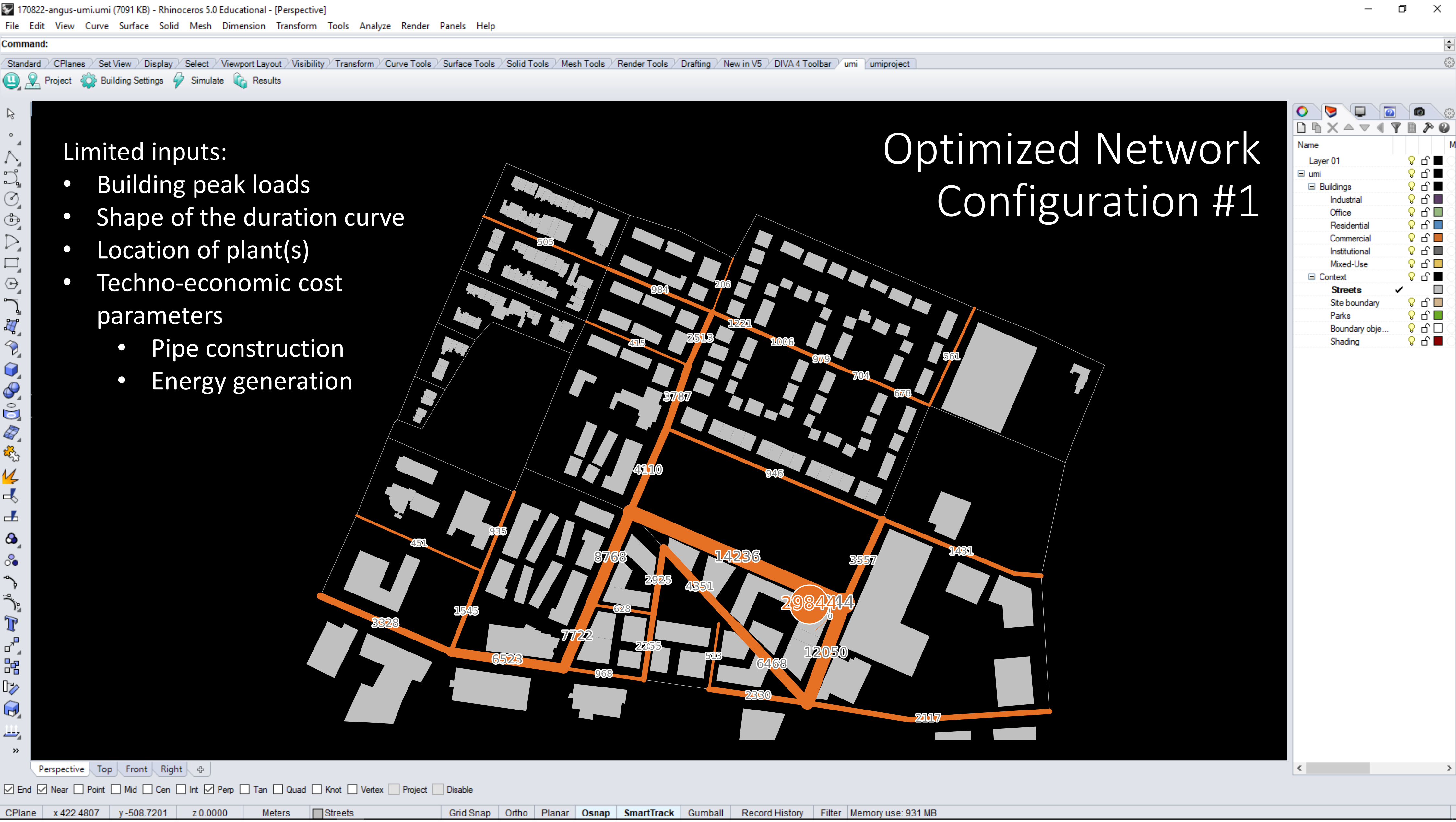
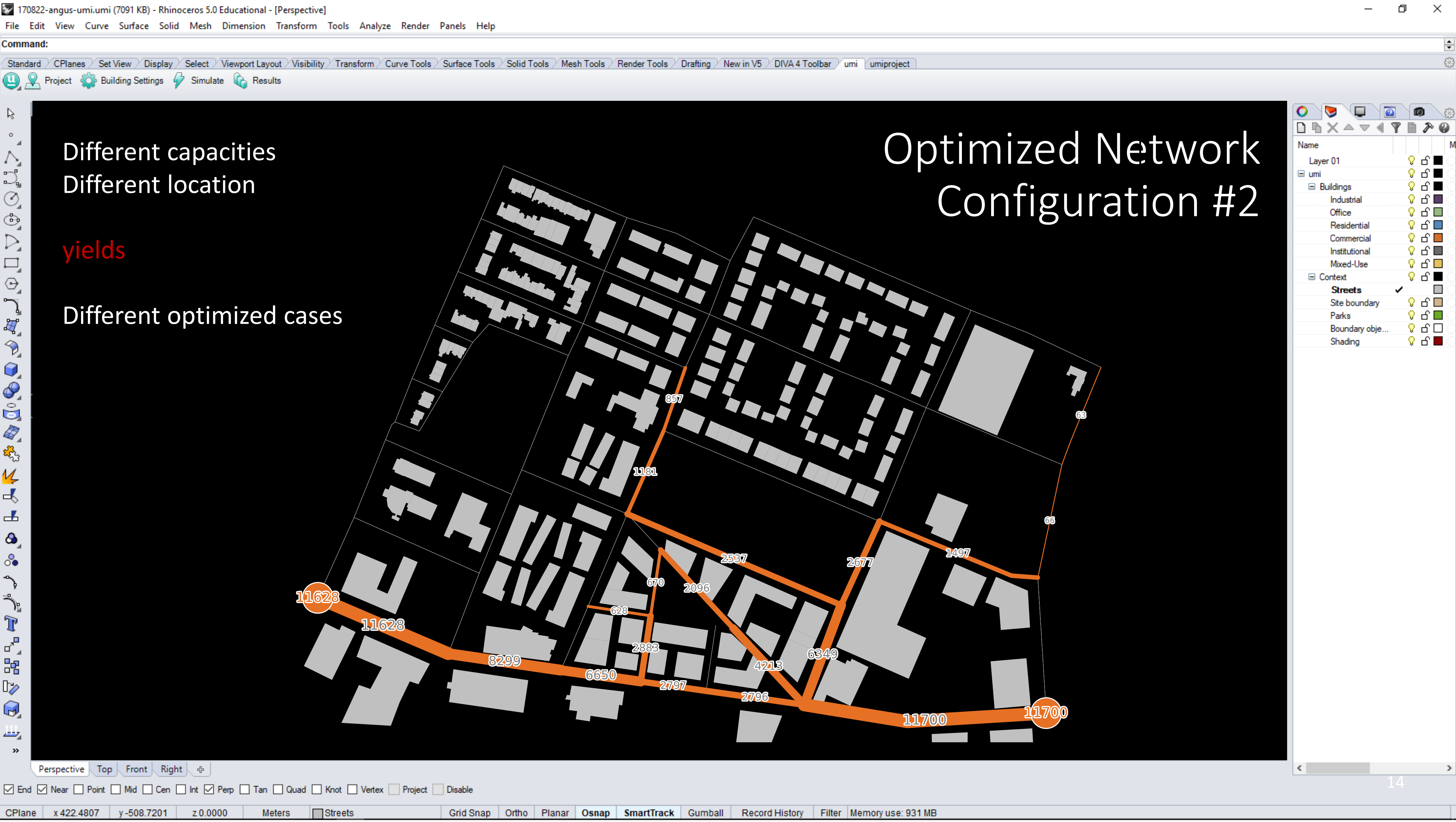
File Edit View Curve Surface Solid Mesh Dimension Transform Tools Analyze Render Panels Help
1 polysurface added to selection.
1 object changed to layer "Heating Network".
Command: ShortestWalk
Select curves meeting at endpoints. Press Enter when done (Topology=Hide Tolerance=0.01 SearchMode=CurveLength):
Less than three lines were selected
Command:
Standard CPlanes Set View Display Select Viewport Layout Visibility Transform Curve Tools Surface Tools Solid Tools Mesh Tools Render Tools Drafting New in V5
Project Building Settings Simulate Results
Top
Layers umi Display
Name Material Linetype
Default Continuous
CONTEXT New mater... Continuous
PARCELS Continuous
umi Continuous
Buildings Continuous
Context Continuous
Streets Continuous
Site boundary Continuous
Parks Continuous
Boundary objects Continuous
Shading Continuous
Mobility amenities Continuous
Grocery stores Continuous
Restaurants Continuous
Coffee Continuous
Shopping Continuous
Banks Continuous
Books Continuous
Entertainment Continuous
Schools Continuous
District Energy Continuous
Heating Network Continuous
Cooling Nerwork Continuous
Top Top Front Right
CPlane x 1075.89 y 980.74 z 0.00 Meters Default Grid Snap Ortho Planar Osnap SmartTrack Gumball Record History Filter Available physical memory: 1864 MB

Optimized Network Configuration #1

Limited inputs:

- Building peak loads
- Shape of the duration curve
- Location of plant(s)
- Techno-economic cost parameters
  - Pipe construction
  - Energy generation




170822-angus-umi.umi (7091 KB) - Rhinoceros 5.0 Educational - [Perspective]
Different capacities
Different location
yields
Different optimized cases
Optimized Network
Configuration #2
11628
11628
8299
6650
2797
2796
11700
11700
857
1181
2537
2677
1497
63
66
670
2096
628
2883
4213
6349
Layer 01
umi
Buildings
Industrial
Office
Residential
Commercial
Institutional
Mixed-Use
Context
Streets
Site boundary
Parks
Shading
Perspective
Top
Front
Right

Other options
Mixed Integer optimization
Binary decision (0: the pipe doesn't exist, 1: the pipe exists)

Energy
Service
COmpany

Objective function

$$z = \sum investment\ costs + \sum (Operation\ costs - revenues)$$

(infrastructure)

(Maintenance, elec. purchase, nat. gas, etc.)

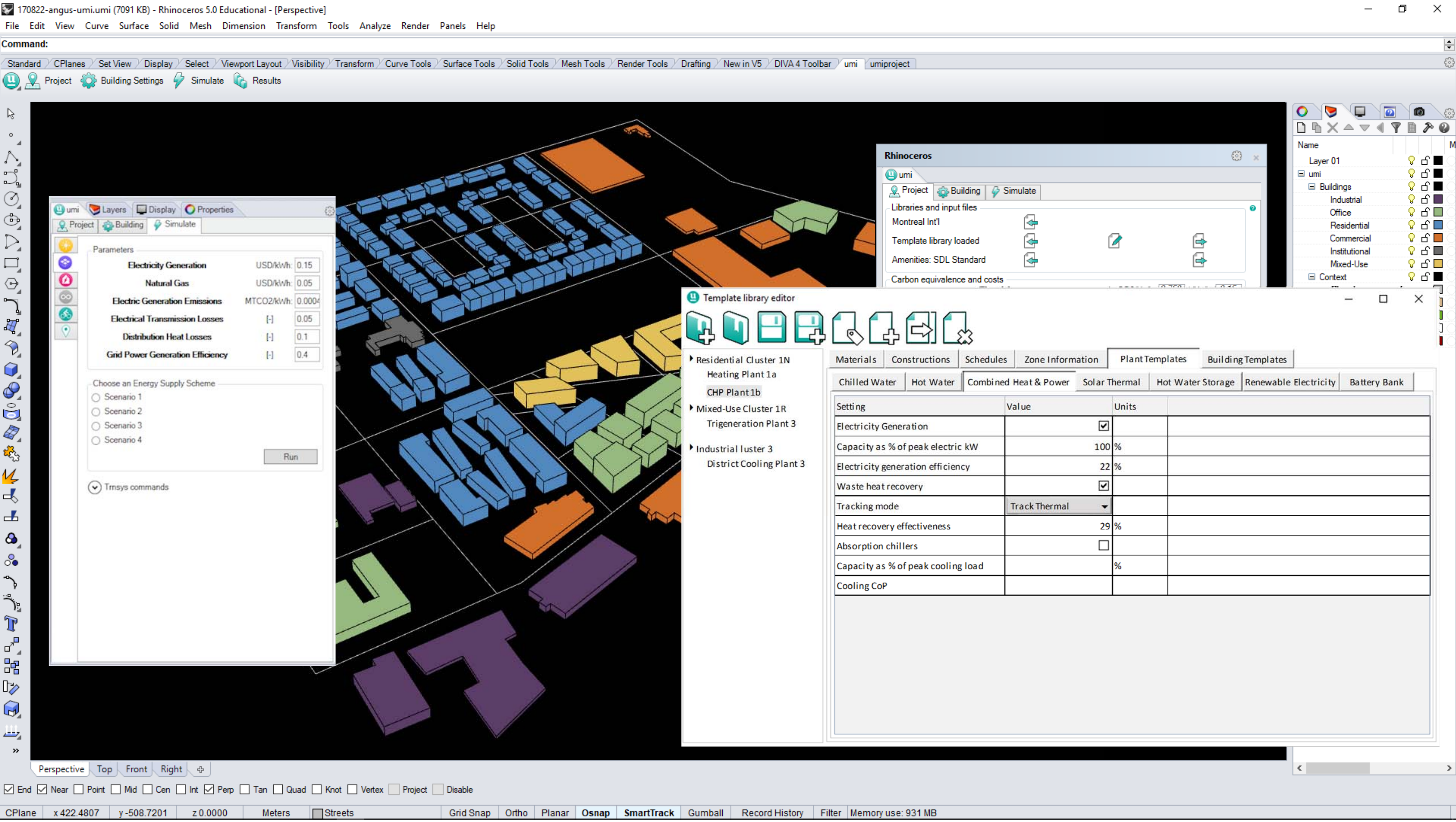
(Energy sold to customers)

J. Dorfner and T. Hamacher, "Large-Scale District Heating Network Optimization," *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1884–1891, Jul. 2014.

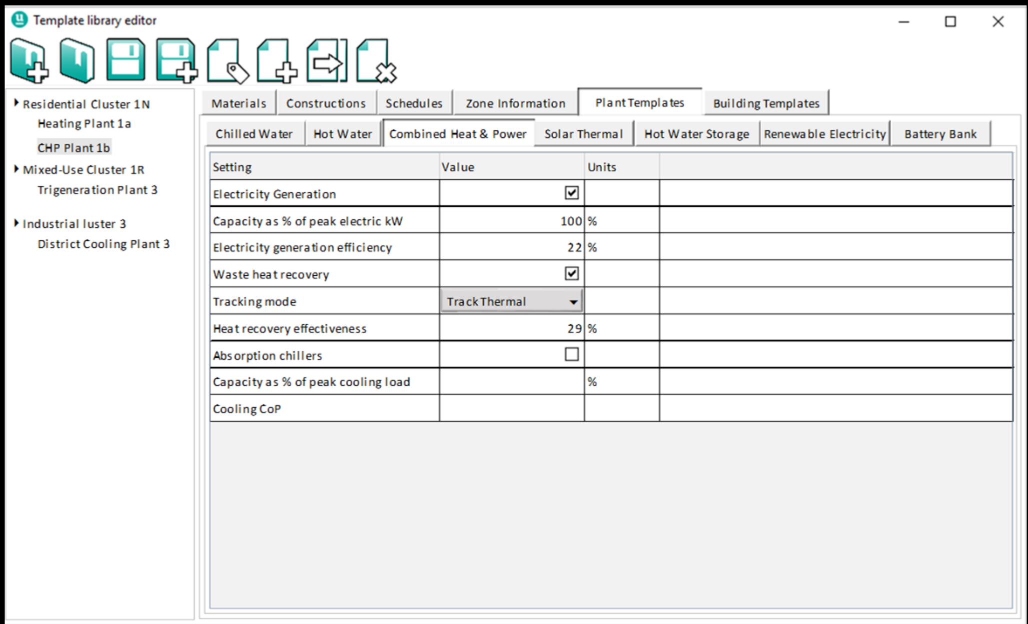
Typical workflow

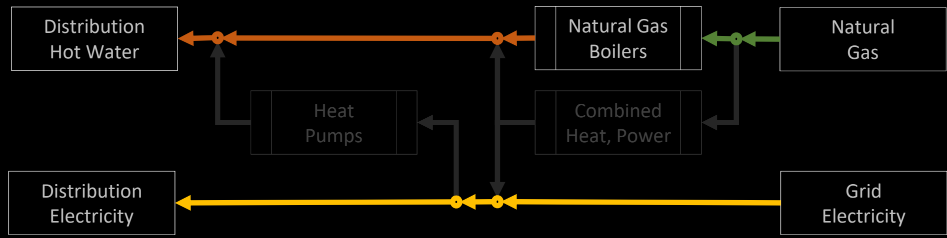
3. Define the supply scheme

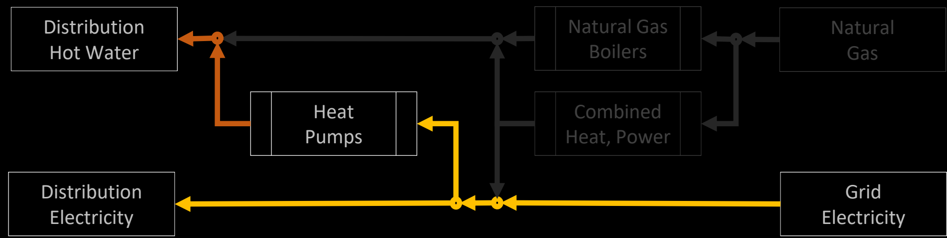
How is the energy generated?

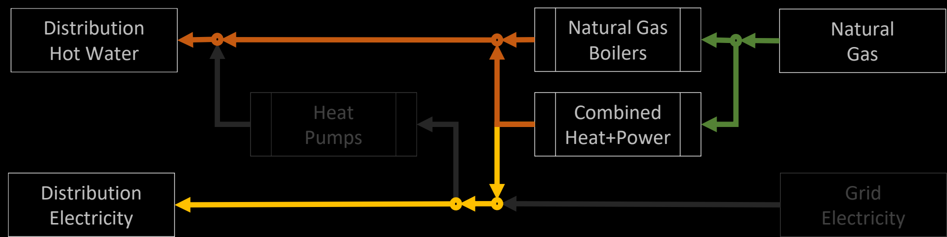

170822-angus-umi.umi (7091 KB) - Rhinoceros 5.0 Educational - [Perspective]
File Edit View Curve Surface Solid Mesh Dimension Transform Tools Analyze Render Panels Help
Command:
Project Building Settings Simulate Results
umi Layers Display Properties
Project Building Simulate
Parameters
Electricity Generation USD/kWh 0.15
Natural Gas USD/kWh 0.05
Electric Generation Emissions MTCO2/kWh 0.0004
Electrical Transmission Losses [-] 0.05
Distribution Heat Losses [-] 0.1
Grid Power Generation Efficiency [-] 0.4
Choose an Energy Supply Scheme
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Run
Trnsys commands
Rhinoceros
Libraries and input files
Montreal Int'l
Template library loaded
Amenities: SDL Standard
Carbon equivalence and costs
Template library editor
Residential Cluster 1N
Heating Plant 1a
CHP Plant 1b
Mixed-Use Cluster 1R
Trigeneration Plant 3
Industrial luster 3
District Cooling Plant 3
Materials Constructions Schedules Zone Information Plant Templates Building Templates
Chilled Water Hot Water Combined Heat & Power Solar Thermal Hot Water Storage Renewable Electricity Battery Bank
Setting Value Units
Electricity Generation
Capacity as % of peak electric kW 100 %
Electricity generation efficiency 22 %
Waste heat recovery
Tracking mode Track Thermal
Heat recovery effectiveness 29 %
Absorption chillers
Capacity as % of peak cooling load %
Cooling CoP
Perspective Top Front Right
End Near Point Mid Cen Int Perp Tan Quad Knot Vertex Project Disable
CPlane x 422.4807 y -508.7201 z 0.0000 Meters Streets Grid Snap Ortho Planar Osnap SmartTrack Gumball Record History Filter Memory use: 931 MB
Name
Layer 01
umi
Buildings
Context

Different supply schemes for different local contexts





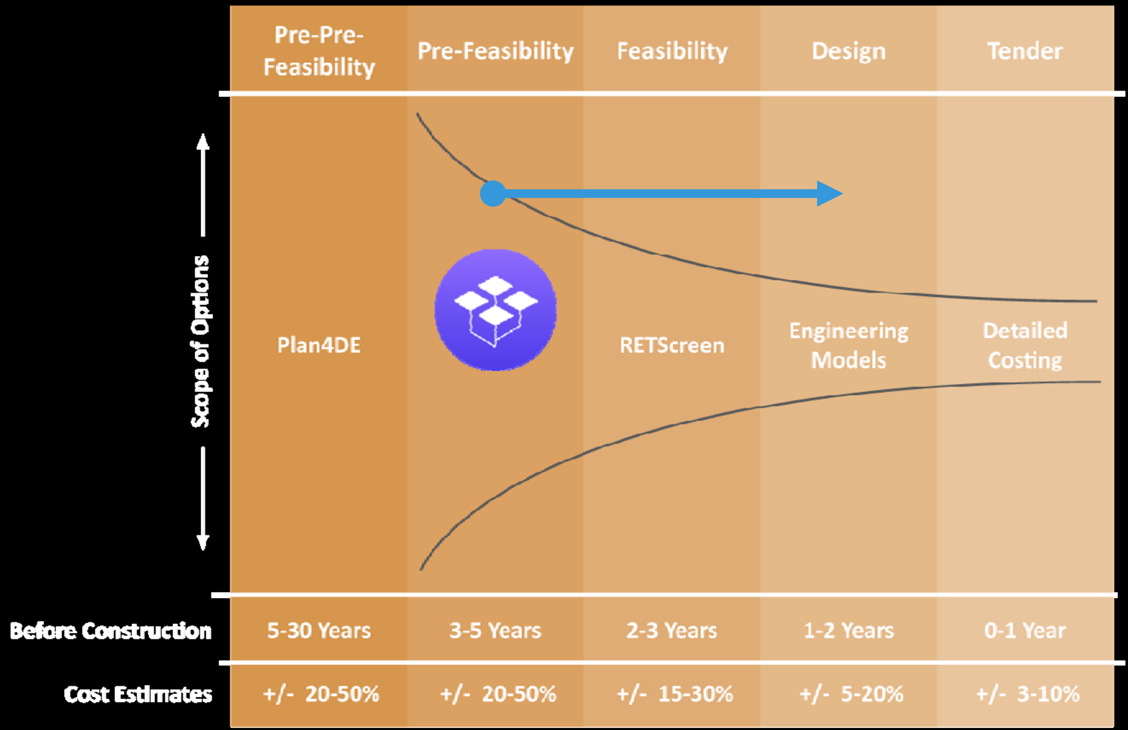




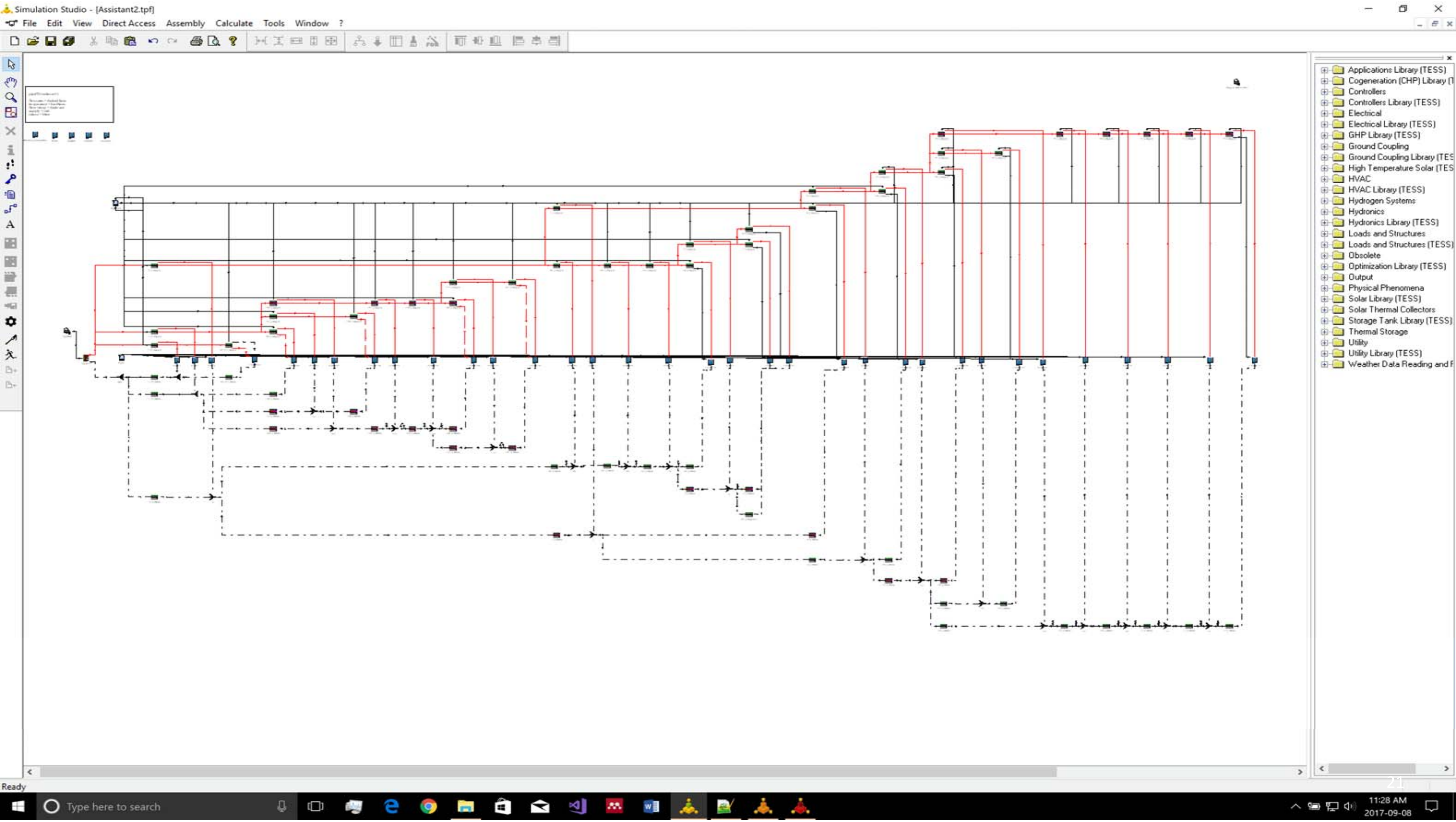
4. Bridging the gap

From early stage design to detailed system design

Different levels of developement

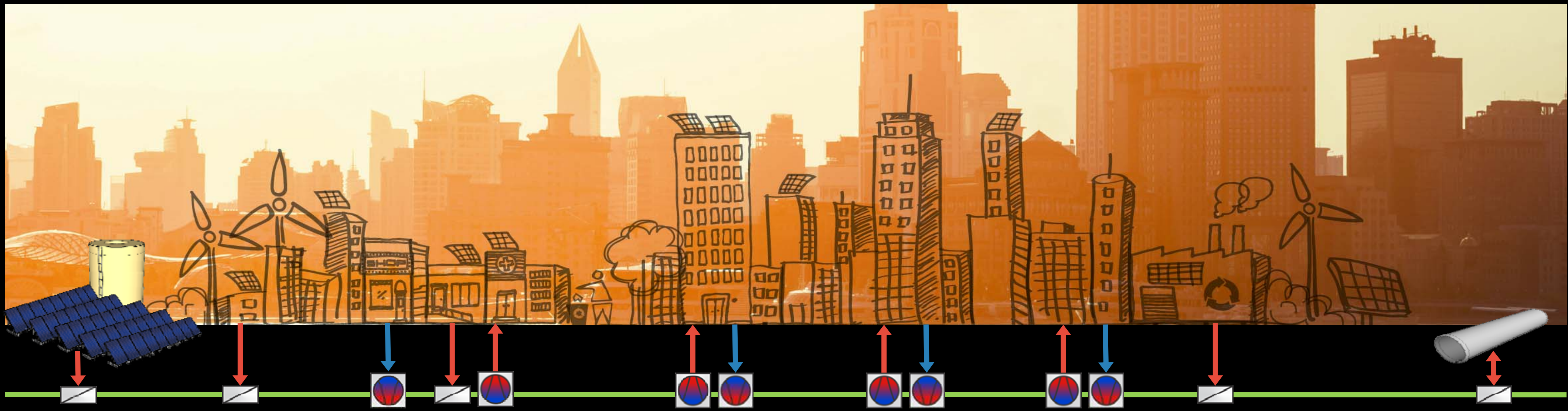


Sustainability Solutions Group, "IEA DHC Annex XI: Plan4DE Final Report," International Energy Agency Energy Technology Initiative on District Heating and Cooling including Combined Heat and Power (IEA DHC), Sep. 2016.



Simulation Studio - [Assistant2.tpf]
File Edit View Direct Access Assembly Calculate Tools Window ?
Applications Library (TESS)
Cogeneration (CHP) Library (T
Controllers
Controllers Library (TESS)
Electrical
Electrical Library (TESS)
GHP Library (TESS)
Ground Coupling
Ground Coupling Library (TES
High Temperature Solar (TES
HVAC
HVAC Library (TESS)
Hydrogen Systems
Hydronics
Hydronics Library (TESS)
Loads and Structures
Loads and Structures (TESS)
Obsolete
Optimization Library (TESS)
Output
Physical Phenomena
Solar Library (TESS)
Solar Thermal Collectors
Storage Tank Library (TESS)
Thermal Storage
Utility
Utility Library (TESS)
Weather Data Reading and F
Ready
Type here to search
11:28 AM
2017-09-08

Next steps. . .



Beyond the 4th generation: mitigated loop, buildings sharing excess heat at the district level (cooling and heating and the same loop)

[Adapted: UNEP, 2015]

In a nutshell. . .

- A tool promoting district energy solutions
- Integrated into a workflow familiar with designers and practitioners
- Bridging the gap between the architectural programming phase and energy planning phase at the district level

Walkability

Bikability

Daylight autonomy

LifeCycle

Operational Energy

District Energy

http://urbanmodellinginterface.ning.com

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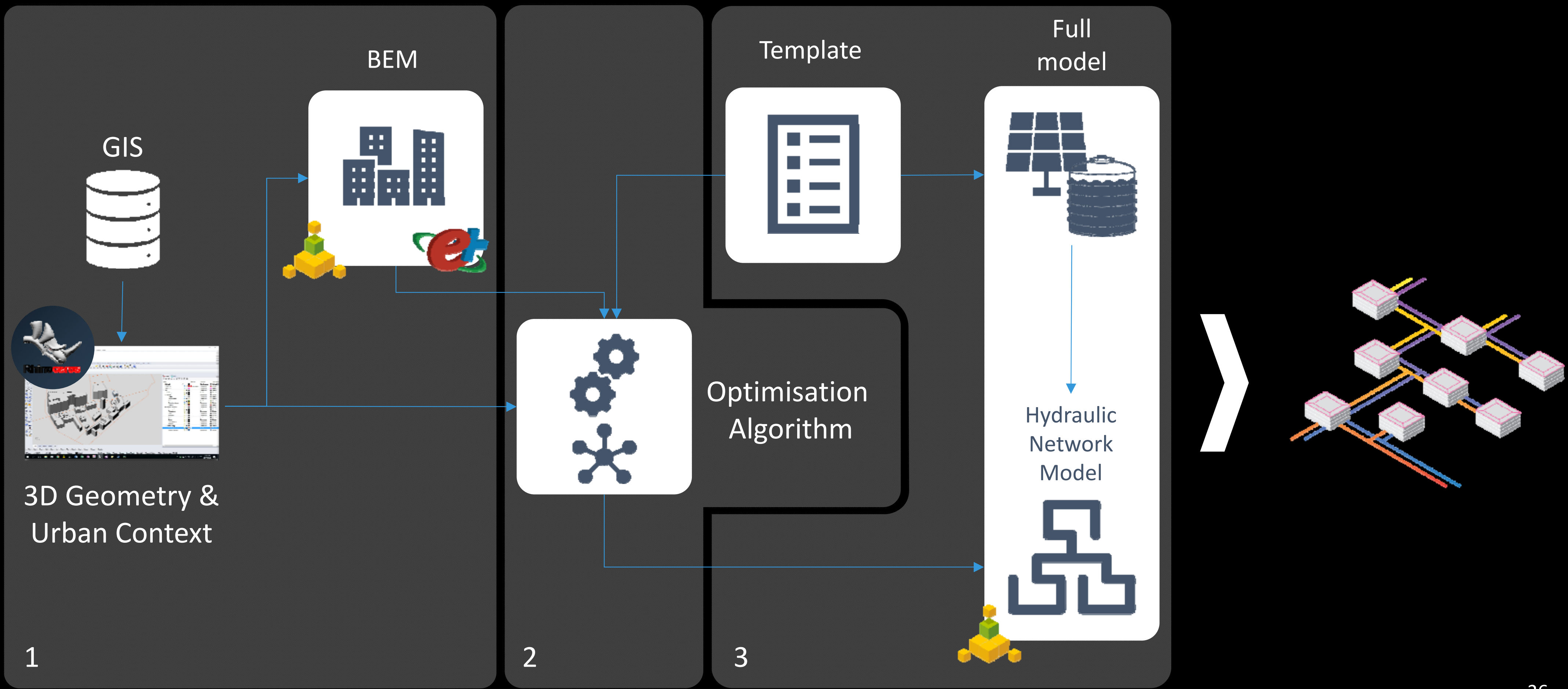
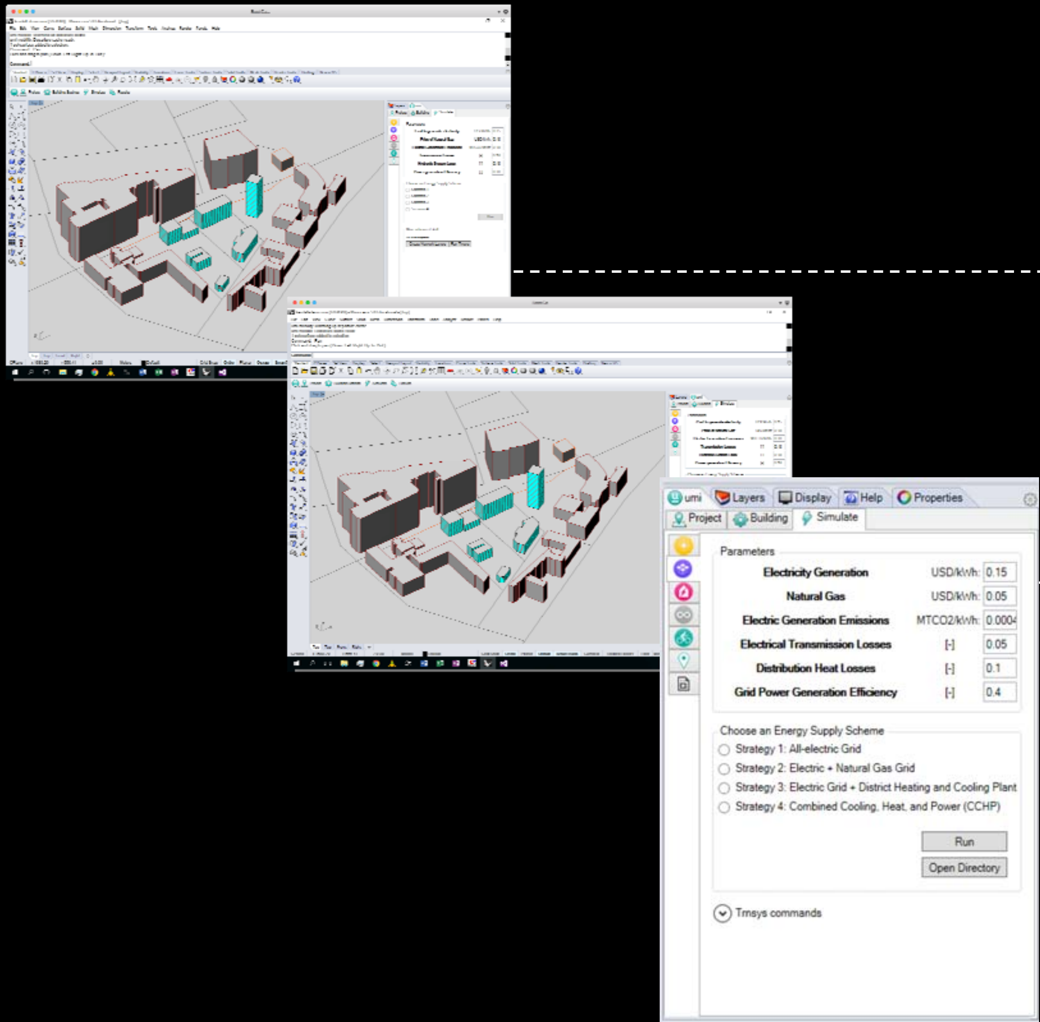
[Montréal hivernal : From: pixabay.com]

References

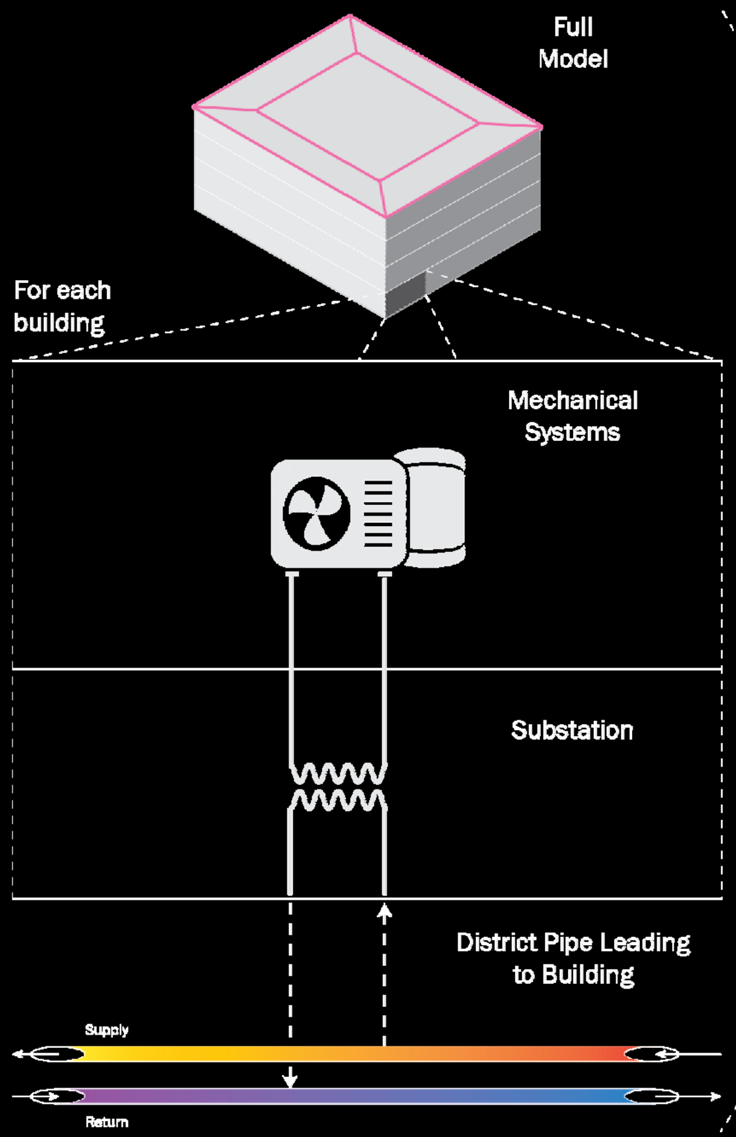
- T. Dogan et C. Reinhart, « Automated conversion of architectural massing models into thermal ‘shoebox’ models », dans Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, Août 26-28, 2013, p. 3745- 3752.
- J. Dorfner et T. Hamacher, « Large-Scale District Heating Network Optimization », IEEE Trans. Smart Grid, vol. 5, no 4, p. 1884- 1891, juill. 2014.
- QUEST Canada, « Building Smart Energy Communities: Implementing Integrated Community Energy Solutions », QUEST Canada, sept. 2012.
- DOE, « U.S. Department of Energy Commercial Reference Building Models of the National Building Stock », National Renewable Energy Laboratory, Golden, Colorado, TP-5500-46861, 2011.
- MIT SDL, « Modeling Boston: A workflow for the generation of complete urban building energy demand models from existing urban geospatial datasets », Sustainable Design Lab, Massachusetts Institute of Technology, 2016.
- UNEP, « District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy », United Nations Environment Programme, Paris, 2015.

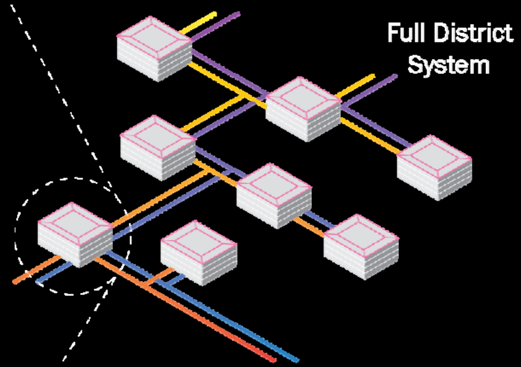
Workflow Scheme



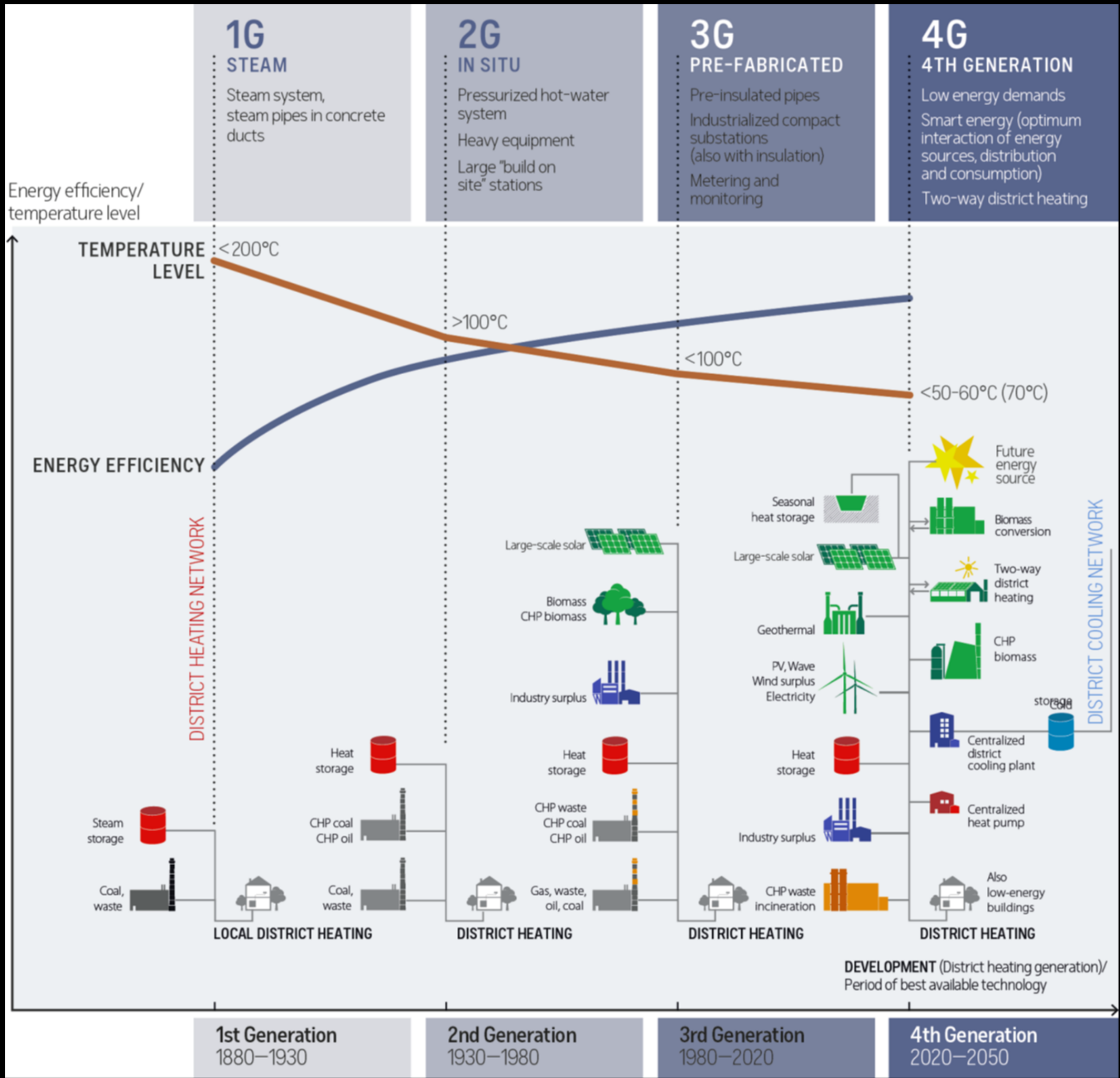

umi
Layers
Display
Help
Properties
Project
Building
Simulate
Parameters
Electricity Generation
USD/kWh:
0.15
Natural Gas
USD/kWh:
0.05
Electric Generation Emissions
MTCO2/kWh:
0.0004
Electrical Transmission Losses
[-]
0.05
Distribution Heat Losses
[-]
0.1
Grid Power Generation Efficiency
[-]
0.4
Choose an Energy Supply Scheme
Strategy 1: All-electric Grid
Strategy 2: Electric + Natural Gas Grid
Strategy 3: Electric Grid + District Heating and Cooling Plant
Strategy 4: Combined Cooling, Heat, and Power (CCHP)
Run
Open Directory
Trnsys commands

Dynamic modelling at different levels

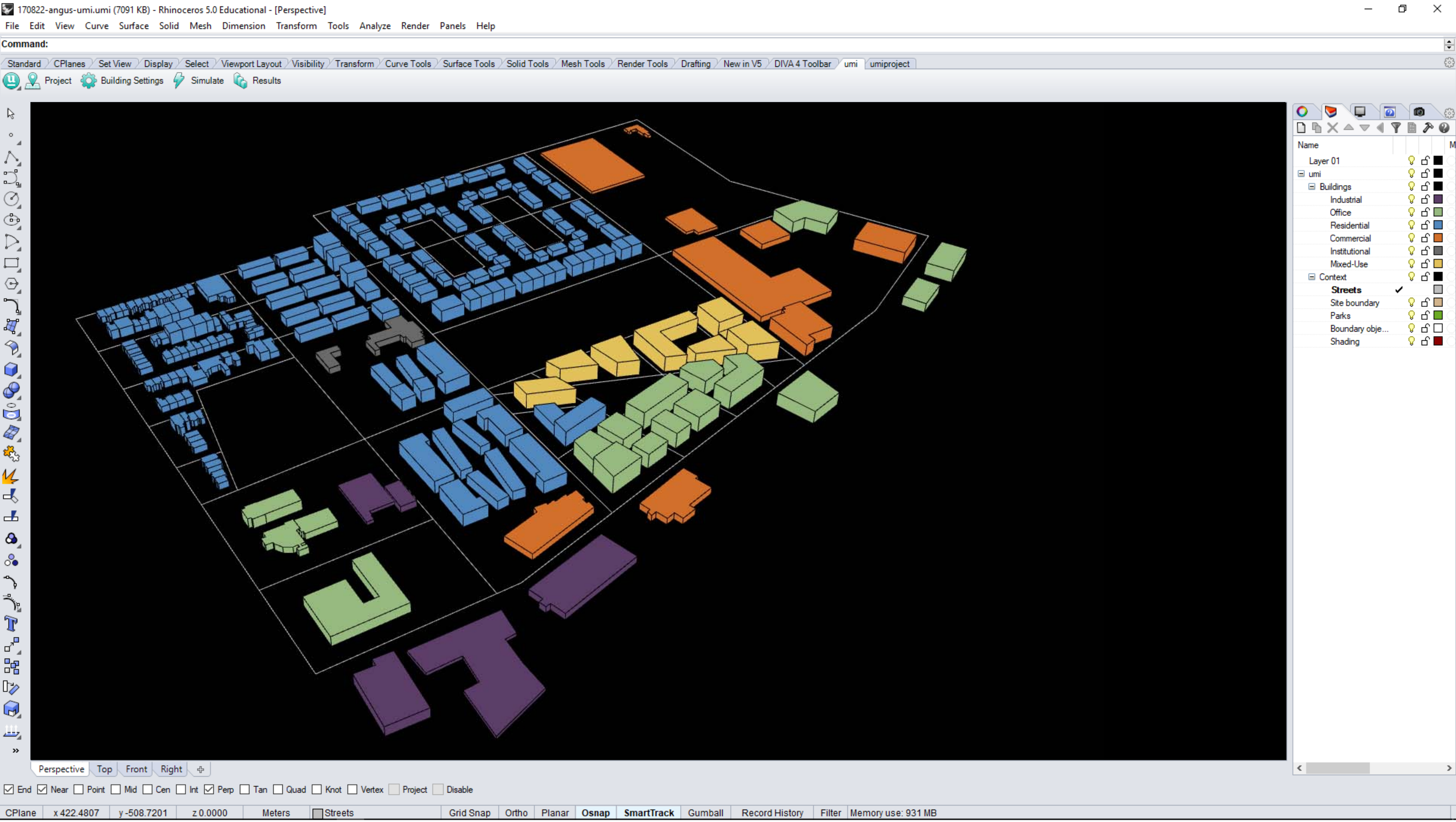


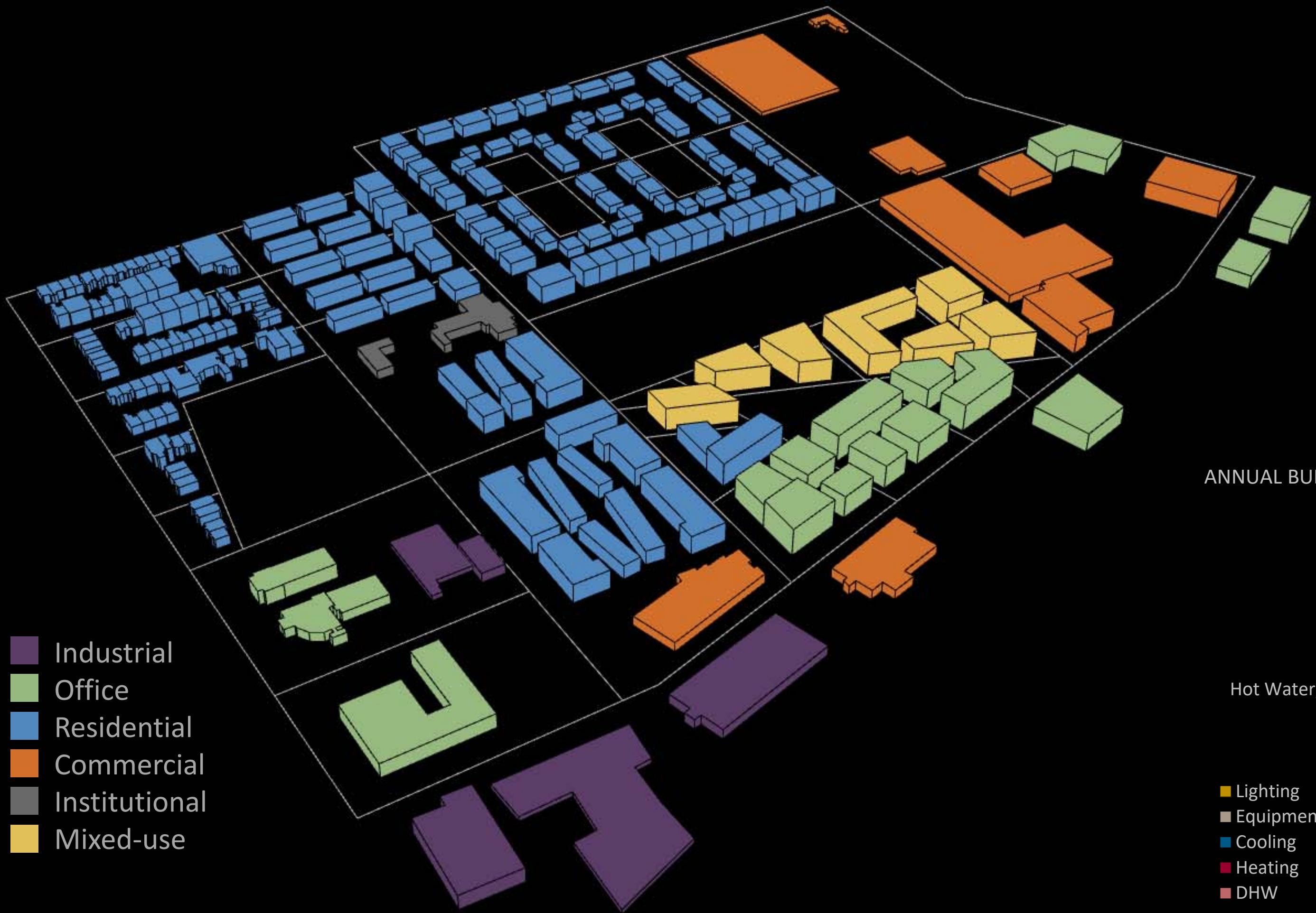


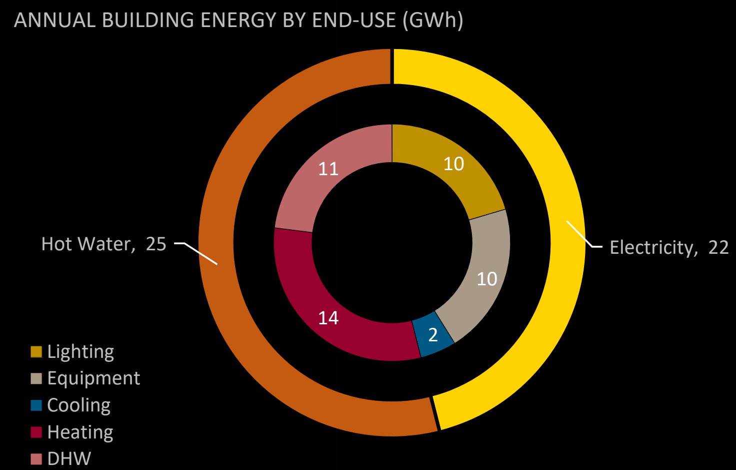
Different district heating generations

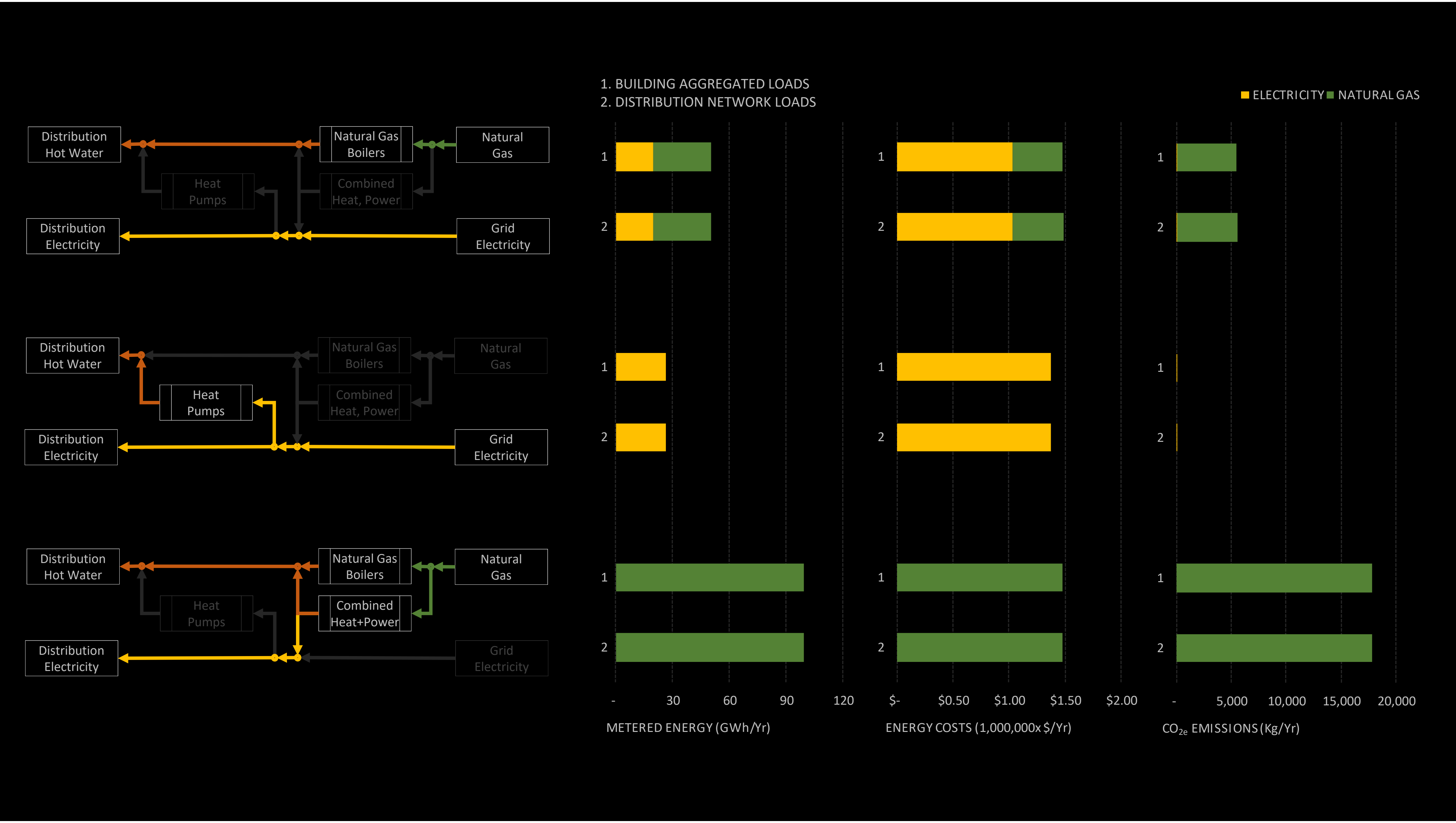


[UNEP, 2013]


170822-angus-umi.umi (7091 KB) - Rhinoceros 5.0 Educational - [Perspective]
File Edit View Curve Surface Solid Mesh Dimension Transform Tools Analyze Render Panels Help
Command:
Standard CPlanes Set View Display Select Viewport Layout Visibility Transform Curve Tools Surface Tools Solid Tools Mesh Tools Render Tools Drafting New in V5 DIVA 4 Toolbar umi umiproject
Project Building Settings Simulate Results
Name
Layer 01
umi
Buildings
Industrial
Office
Residential
Commercial
Institutional
Mixed-Use
Context
Streets
Site boundary
Parks
Boundary obje...
Shading
Perspective Top Front Right
End Near Point Mid Cen Int Perp Tan Quad Knot Vertex Project Disable
CPlane x 422.4807 y -508.7201 z 0.0000 Meters Streets Grid Snap Ortho Planar Osnap SmartTrack Gumball Record History Filter Memory use: 931 MB


Industrial
Office
Residential
Commercial
Institutional
Mixed-use


ANNUAL BUILDING ENERGY BY END-USE (GWh)
Hot Water, 25
Electricity, 22
10
10
2
14
11
Lighting
Equipment
Cooling
Heating
DHW



1. BUILDING AGGREGATED LOADS
2. DISTRIBUTION NETWORK LOADS
ELECTRICITY
NATURAL GAS
Distribution Hot Water
Natural Gas Boilers
Natural Gas
Heat Pumps
Combined Heat, Power
Combined Heat+Power
Distribution Electricity
Grid Electricity
1
2
- 30 60 90 120
METERED ENERGY (GWh/Yr)
$- $0.50 $1.00 $1.50 $2.00
ENERGY COSTS (1,000,000x $/Yr)
- 5,000 10,000 15,000 20,000
CO2e EMISSIONS (Kg/Yr)