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Building Physics: Comparison on Different Technical Solutions for Facades

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GTB CONSTRUCTION

BUILDING PHYSICS : COMPARISON ON DIFFERENT TECHNICAL SOLUTIONS FOR FACADES

Master's Thesis

Lund Tekniska Högskola

Spring 2009

The aim will be to compare the thermal efficiency, air tightness and water tightness of different façades. A large part will show the influences of having the good method to build the façades and the bad sides it can involve on a long term if this method is not properly used.

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Introduction

When time came for me to go through my master's thesis, I had several solutions. Either to stay in a laboratory and write about something very technical and accurate in building physics (as I could do it in LTH), either to have an internship on a building site.

I chose the second possibility, since I wanted to understand building physics at the last part of its chain: the construction site.

A great opportunity was given to me on a construction site in Nantes (western France), which taught me how to build both on a structural point of view and a physics orientated point of view.

In this report, I will present the different steps we took on the building site as for façades and try to show how every step could have an influence on the energy efficiency of the future building. I will also present you the first prefabricated façade elements we laid on a prototype, a 15m² building built for the client to be able to show its potential future tenants how the offices will look like (see sketches in annex 4).

I will also try to point which kind of "field mistakes" can explain a gap between the studies forecasts and the final constructed building.

THE COMPANY

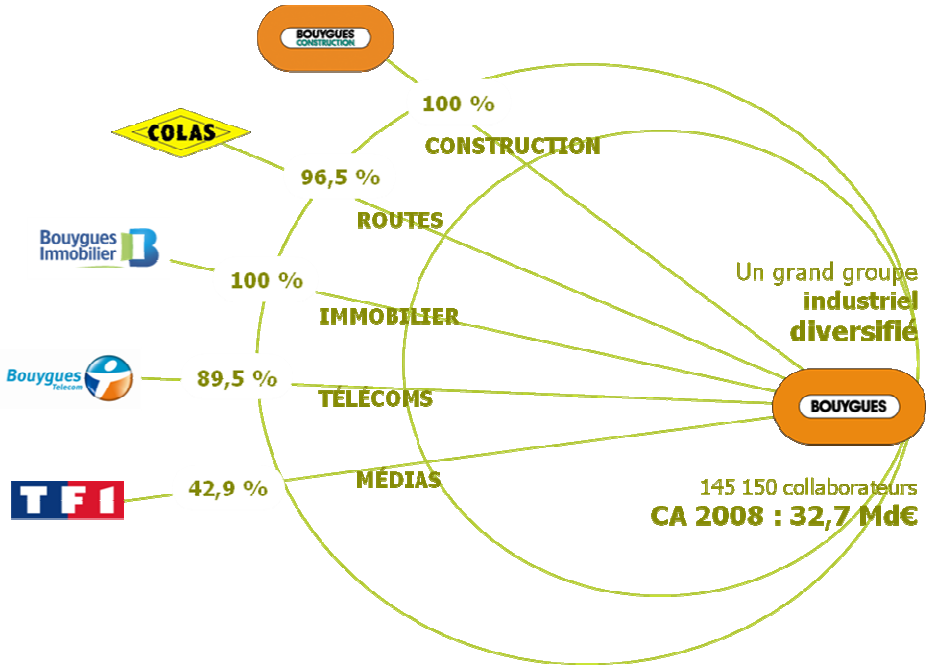
Picture 1 : F. Bouygues, the company creator

History of the BOUYGUES group

In 1952, Francis BOUYGUES created the company, specialized in building construction in Paris.
In 1965, the company bought some local businesses to create a network allover France. It got then a wider activity, with bridges and road construction.
In 1970, the company is registered at the Paris stock exchange and 5 years later, it created the international subsidiaries.
Until this day, the company's turnover kept going up, especially in year 2000 where its capital reached 19 billion Euros.

The BOUYGUES group activity

Established in 80 countries in the world, the BOUYGUES group has around 150 000 employees and had a 32, 7 billions Euros turnover in 2008. Roads and Construction represents 66%of this turnover. Here are the different trades of the BOUYGUES group with the proportion of shareholding:



Picture 2 : The BOUYGUES group

Bouygues construction is one of the biggest buildings constructor including electricity systems.

Colas is the world biggest constructor for roads, bridges, transport infrastructures city planning and landscaping.

Bouygues immobilier is a big property developer in France and Europe which develops projects as housing, offices buildings and shopping centers.

Bouygues Telecom is a mobile/internet/TV operator.

TF1 is the biggest TV channel in France.

GTB Construction

Bouygues Construction which was focused on Paris untill 1970 decided then to extend its activity all over France to have subsidiaries everywhere. That's why they bought tree companies (Quemeneur, Peniguel and Bouyer) which became the biggest construction company in the north west of france. In 2004, it took its today name GTB Construction and work on the region underligned in white bellow:

Picture 3 : establishment of the BOUYGUES Construction's subsidiaries

Picture 4 : development section of GTB Construction

Activities:

GTB-Construction acts as the overall coordinator on both private and public construction sites and has its own workers and site managers for the carcass. It has a property development service, commercial service and a engineering department which enable to be present from the beginning to the end on a projects as:

- Housing buildings
- Services buildings as hospitals, jails, schools and universities, hostels, offices and shopping centers.
- Restoration of any type of buildings
- Industry and environment
- Property development

GTB Construction represents 53 700 employees all over the world and had a turnover of 9, 5 billions Euros last year.

Presentation of the building site

The future building

The whole project represents **20 000 m²** of offices mainly, with some stores and restaurants at the bottom floor as well. A part of the buildings (about one third) will be the head office for our own company which gave the building site a bigger importance and which gave the opportunity to meet our directors several times. It is located just next to the Nantes's train station which gives this offices building a strategic position for its future tenants.

The whole construction will last **2, 5 years**, to be achieved in November 2010, and cost **47 million Euros**.

Picture 5 : The future building

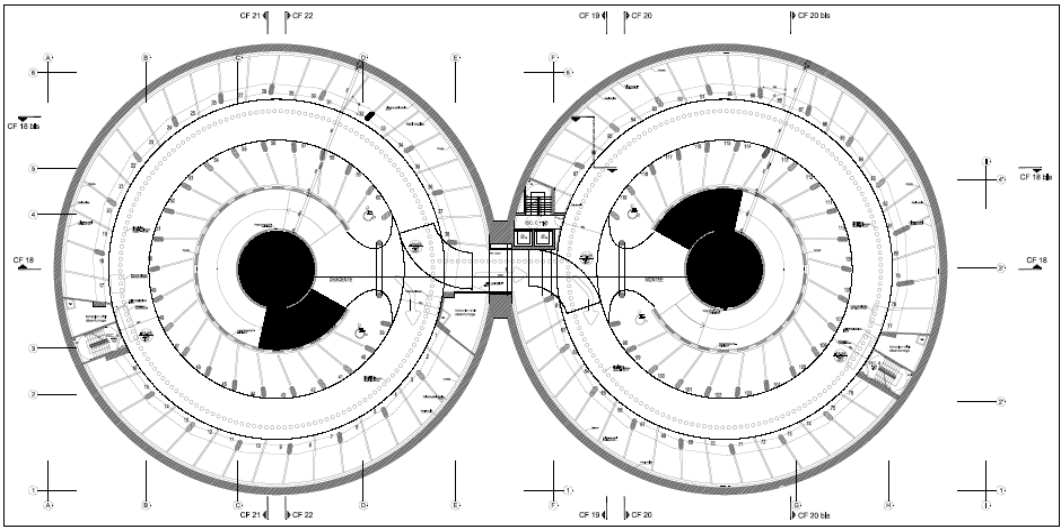
Picture 6 : And by night…

Infrastructure

Presentation

An important part of the construction is underground. The building is indeed located near the river *La Loire,* which involved that the groundwater is 3meters below the ground. However, we had to dig until -12 meters deep and consequently to pump water to lower it from about 9 meters.

The six floors underground will be a **28 000m²** car park which will contain **670 cars**. Here is a sketch of one of the floors:



Picture 7 : sketch of the underground car parks

The works

Since we were next to this river, most of the ground composition was sand mixed with stones. It would have been impossible to dig it from the ground surface, since it would have collapse and water would have been very hard to pump. They also built two walls shaped like cylinders (diaphragm walls) which were casted in the soil itself, side by side, considered to be water tight and enabling to remove materials only inside the walls (picture 8).

When earth was removed, foundations piles were made to sit on the building and a big concrete slab was cast on them. Some areas of this slab receive traction strengths do to the water pressure and we had to dig micropiles (small steel piles fastened in the rocks and working in traction) to face it.

Then, traditional floors were made, with a prop in the middle of each cylinders enabling car to go up or down in the car parks.

Here are the different stages during the underground construction:

- ✓ Digging of the diaphragm wall with insertion of bentonit (mixture of cement and clay)

Picture 8 : diaphragm walls digging

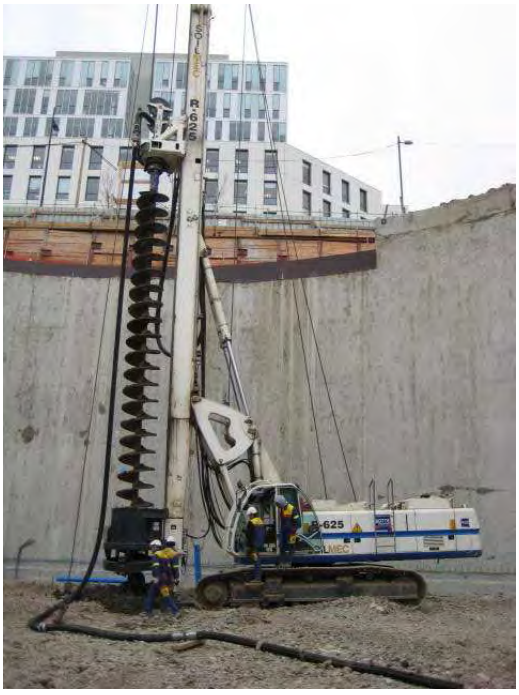
- ✓ Pouring of concrete to replace bentonit

Picture 9 : concrete pouring

✓ Digging of the soil inside the diaphragm walls

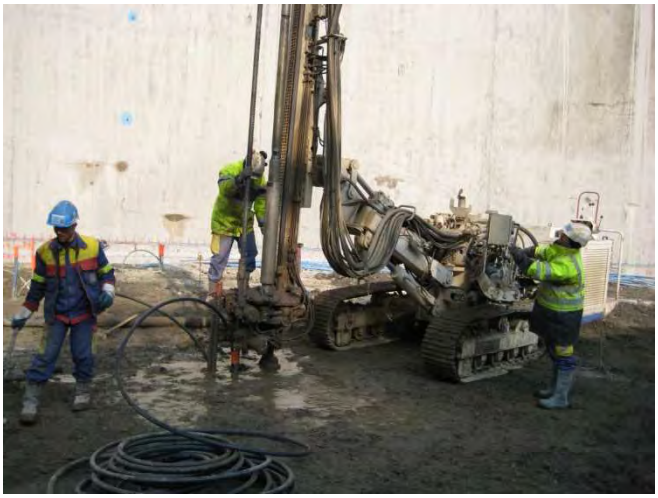
Picture 10 : Soil digging inside diaphragm walls

✓ Digging of the piles



Picture 11 : Piles achievement

✓ Digging of the micropiles



Picture 12 : Achievement of micropiles

✓ Casting of the thick bottom slab

Picture 13 : Achievement of the bottom slab

✓ Casting of the floors slabs

Picture 14 : Achievement of the floors slabs

Superstructure

Presentation

The superstructure will be made of two buildings (see annexe 1)

The infrastructure carcass work will last around one year. Then the superstructure starts.

It is rather simple: stairs and lifts wells in the middle of the buildings to carry half of the floor loads and to make the whole building more stable. Then prefabricated façades will carry the other half of the floor loads. The floors are made of pre-stressed prefabricated concrete as well.

The external skin of the façade is made of white polished concrete, as it can be seen on picture15. This picture was made on the prototype panels.

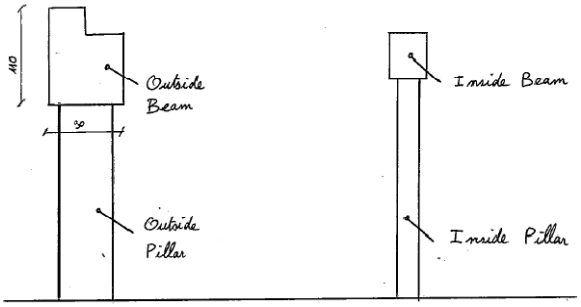
Picture 15 : Look of the future white polished concrete façades

The works

The works on the superstructure are rather simple since there are very repetitive between floors. We finally decided to have prefabricated façades supported by massive beams and pillars at the bottom floor. In the middle of each building, there are lifts wells which take both half of the load off slabs and which enable to make the building stable.

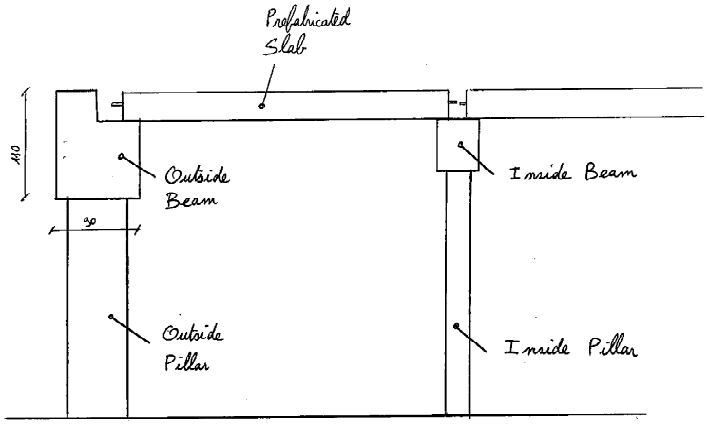
Here are the different stages during the superstructure construction:

- ✓ Achievement of pillars and beams



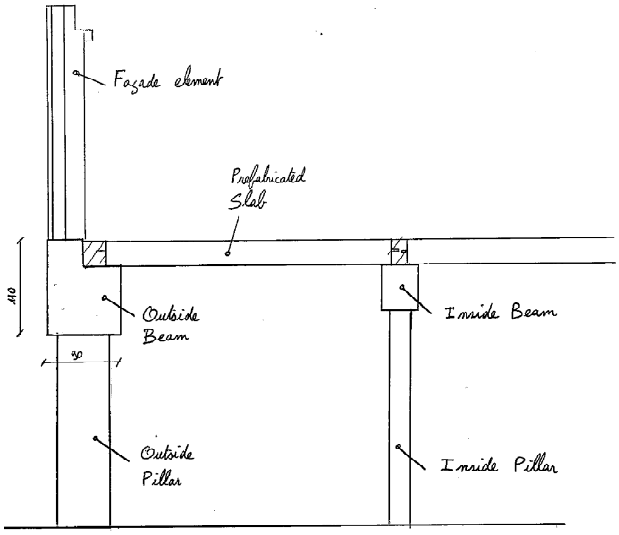
Picture 16 : Achievement of pillars and beams

- ✓ Laying of prefabricated slabs



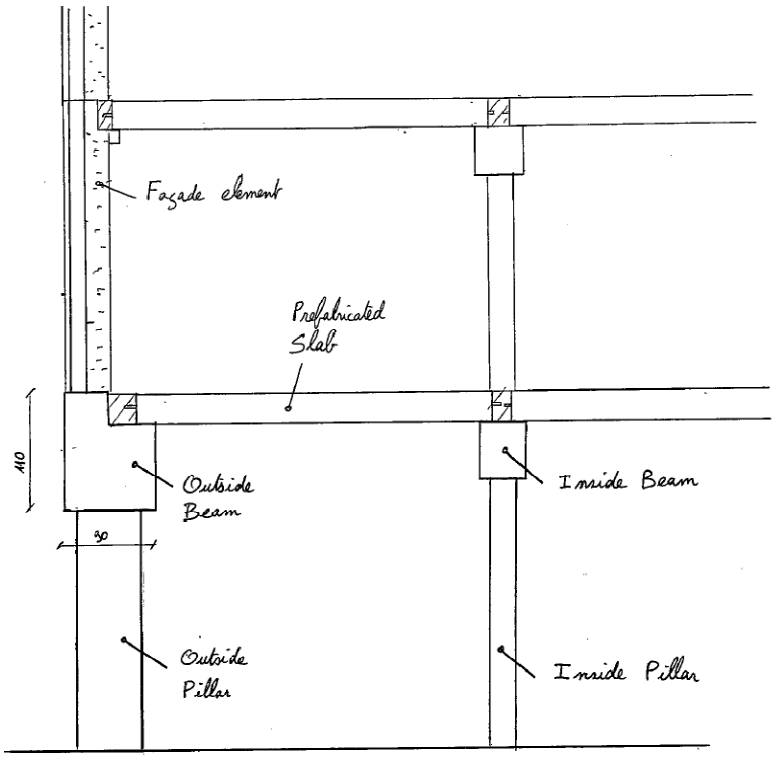
Picture 17 : Laying of prefabricated slabs

- ✓ Laying of prefabricated wall elements



Picture 18 : Laying of façade elements

✓ Laying of prefabricated slabs/walls/slabs etc…



Picture 19 : Laying of slabs/walls/slabs etc..

My missions

Acting as a site manager on the building site, I had several duties. It was besides interesting to have to deal with several issues at the same time, and very instructive on an organisation point of view.

Façades

First, I took part in the study and company consultation on several façade solutions. Double-skin walls, prefabricated sandwich elements or regular poured concrete walls were also compared on different aspects. This was a very instructive period since I had to deal at the same time with planning, technique and money. It was a successful point in my internship since I finally managed to save 15 % on the overall market by using trade competition (around 200 000€).

It taught me that to be a good site manager you really need to know all the technical points of the building sites, especially during the company consultation stage.

Also, when we chose the subcontractor, I was in charge of checking the sketches with him and to give my agreement to start the manufacturing in interaction with the architect and the client (see annexe 2). Again a very instructive duty which helped me to read quickly sketches and to work in complete autonomy.

This façade mission, which took me more than half of my time during this internship, will remain as my best duty since it was a way to apply the knowledge I received during my education. Thanks to this knowledge, I received certain credibility from my colleagues which gave me more and more autonomy.

Infrastructure works

At the same time, I was in charge of paying attention to several subcontractors working in the infrastructure : diaphragm wall, piles, micropiles…

That duty forced me to be quiet often on site to have a look after our subcontractor during March, April and June mainly. This time, I had nothing to design but just to think about a good method to control the works being processed. That mission taught me one important point: it is with the workers that I will learn the most practical things. It took me a while to understand how to speak to them so that they completely trust me, but I think I can say I got a real complicity with workers at the end. In a word, a really instructive part of my internship on a management point of view.

Environment rules

Finally, I was in charge of the implementation of the HQE environmental rules (High Environmental Quality building) on the construction site. That was about taking care about construction wastes and their recycling, about energy consumption on site and any issue that could reduce the ecological print of the construction site.

If the mission looked nice, I didn't have enough time to make a real profit from it. It was indeed a lot of administrative work, like collecting documents of construction materials, writing tables with energy consumptions or wastes production.

One of the only things I will remember from this mission is that the administrative side of these new environmental rules remains to be developed on building sites in France.

Comparison on several façade properties

The compared façades

In this part, I will explain the choice we made right the beginning (just when I arrived on site) as for facades. As you will see, we had to choose (among the site managers team) the technical solutions to use, which was a great chance for me. Indeed, the technical solutions are almost always chosen quite before the construction starts and the site managers only follow these ones. In my case, the construction site team had a real importance on the studies phase.

Traditional poured concrete solution

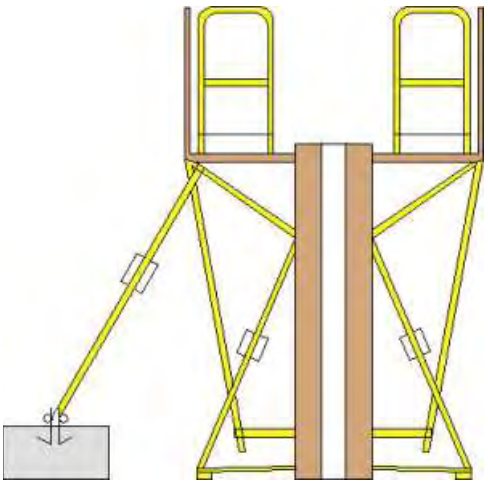
This construction process has been the most common in France during the last 30-40 years. The concept is well known: we set two shuttering panels facing each other and we cast concrete in between. The day after, we remove them with a crane and then start another wall.

Picture 20 : Picture of shuttering panels

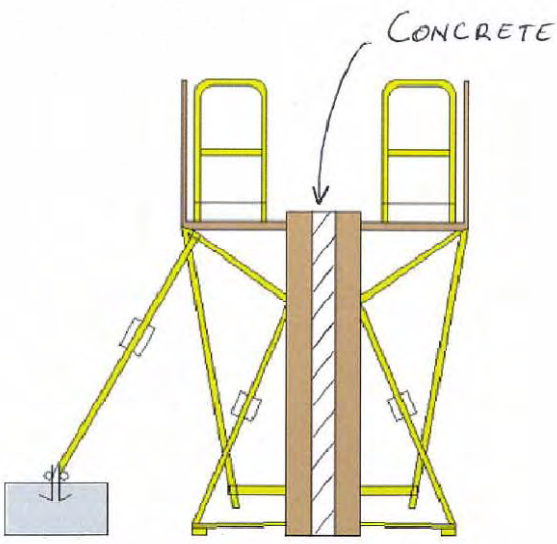
Then, to have the external insulation, polystyrene elements are added on the concrete structural walls.

Finally, to have a polished white concrete appearance, we need to hang prefabricated elements. We suspend these elements with metal parts.

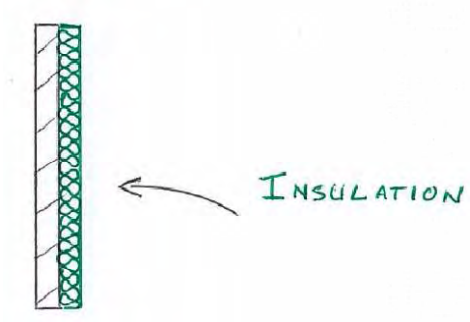
Here is the process illustrated with some drawings:



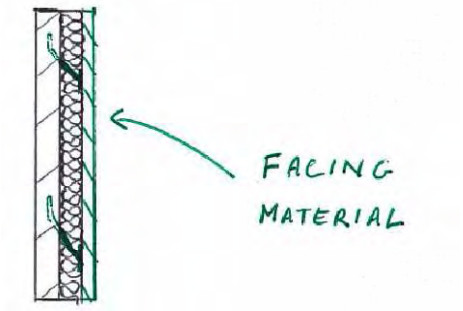
Picture 21 : PHASE 1 → Setting of shuttering panels



Picture 22 : PHASE 2 → Pouring of concrete



Picture 23 : PHASE 3 → Setting up of the insulation



Picture 24 : PHASE 4 → Setting up of the facing material

Sandwich elements

This technology is completely different since almost no concrete is cast on site. To an inside layer (25 cm thick regular concrete) are added the insulation and an outside skin (7cm white concrete) right at the factory. The whole façades are also made of prefabricated elements only put together on site with the crane.

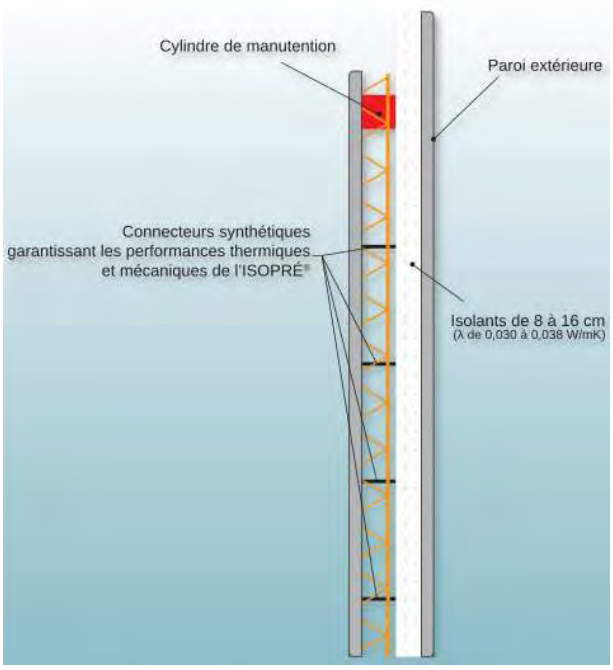
Picture 25 : example of sandwich element

The only concrete which has to be poured on site will be at the junction between elements, to make the elements interdependent.

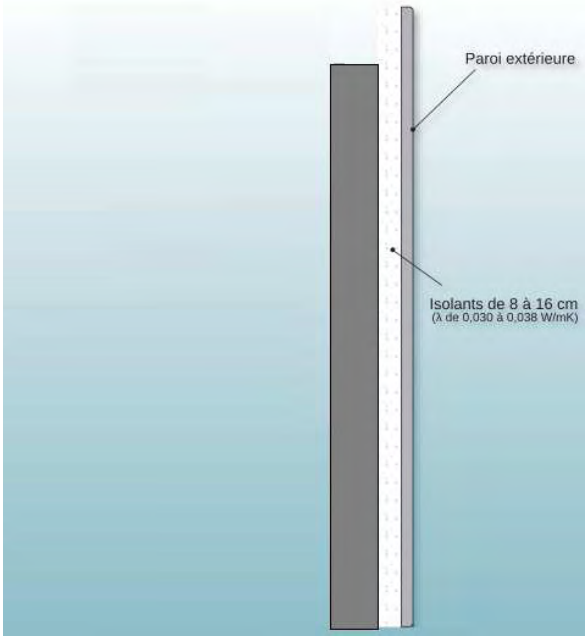
Double skin façade

The technology is in between the two other ones: this is like a sandwich element whose inside layer is only made of two thin skins. There is also a gap to fill in on site with cast concrete. The asset is that prefabricated elements are lighter than regular sandwich elements which gives the opportunity to lift bigger elements with the GRUE.

This technology is really new in France and has never been used by our company in the past.



Picture 26 : Double skin wall before concrete pouring



Picture 22

Our choice

When our commercial service sold the building to the client and its architect, they presented a project with the double skin walls solution. The site managers also received the budget for this solution. This technology had a hidden “social” asset. It was indeed a good way to give some work to our own workers when time would come to cast concrete, which is dramatically important during this economic crisis period where the company is struggling to get new construction sites.

However, prefabricated elements constructors never got a legal recognition yet for these elements even if they told our company they were about to get it when we designed the building. Our insurances also didn’t want to get involve which such technologies and we had no other choice than to look for another solution.

The second choice made by our BE was the traditional one. If this solution wasn’t a technical problem for our company, that was the longest one to carry out. However, we have a very short deadline for the whole building and we couldn’t afford being late during the construction process. Therefore, having chosen this technology would have involved a “twice 8 hours per day” work, meaning that we would have had to work by night (especially during winter). We (the site managers team) didn’t want of this technology, considering that it would have been too hard and too long to hang prefabricated facing prefabricated skins plates by night and especially to line them up. It increased the risks for the workers as well, and was finally the most expensive solution.

Therefore, in January (when I started my internship), we decided to set sandwich elements. The main asset of this solution was the delivery time: we could save almost 4 months on the whole process compared to a traditional cast concrete technology (enabling therefore to work only during daylight). Moreover, this technology is especially adapted to our facades, since we have a lot of repetitive small elements which can be all lifted by the crane.

If this solution is probably rather usual in countries like Sweden, this is a quiet new technology in France. For instance, almost none single family houses are built with sandwich walls today. This is due to the fact we have just now a new legislation about energy efficiency of new construction which press us to use outside insulators. The traditional way was to lay prefabricated elements and then to add insulation from the inside.

Thermal efficiency

Climate in Nantes

Nantes is located on the west coast at around 50 kilometers from the Atlantic Ocean. It also has an oceanic climate, that is to say a rather warm winters and cold summers, with quiet a lot of rain (790 mm/year).

Picture 28 : Climates in France

MONTH	Average temperature in ℃	Average precipitations in mm	Number of days with more than 1 mm rain	Monthly insulation in minuts
janv-03	4,3	87,2	10	6061
févr-03	5,7	63,6	10	6187
mars-03	11,1	30,4	4	11651
avr-03	12,4	30,8	2	12269
mai-03	14,5	55	7	11523
juin-03	20,4	53,2	8	12842
juil-03	20,2	67,8	8	12964
août-03	23,6	15,4	2	17536
sept-03	17,8	50,8	6	13913
oct-03	11,2	92,2	10	6988
nov-03	10,3	108	14	4944
déc-03	6,7	80	9	5254
Average	13,2	61,2	7,5	10178

Picture 29 : climate data in Nantes

Study of the envelop

Theoretical U value

As said before, two buildings will be constructed side by side. The envelop U value for these buildings are supposed to be respectively **U1= 0,813W/K.m²** and **U2= 1,025W/K.m².** (values calculated during the study period). As for the windows, their overall U value is Uw=2,3W/K.m² and their solar factor FS=0,4.

However, the calculation of these values was made quickly during the selling and design process of the building and doesn't include the effect of thermal bridges involved by construction solutions.

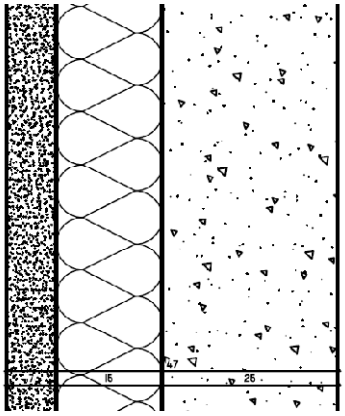
The calculation was made this way:

$$Utot = \frac{Wall\ Area * Uwall + Window\ Area * Uwindow + Roof\ Area * Uroof + Floor\ Area * Ufloor}{Total\ Area}$$

Let's calculate it again for the first building, with the characteristics that have been finally decided by the site managers team.

- WALL

Here is a wall section with its materials, with from the inside to the outside:



Picture 30 : section of walls

Rsi = 0,013 m².K / W

25 cm reinforced concrete, $\lambda = 2{,}5\ \mathrm{W/m.K}$

15 cm polystyrene, $\lambda = 0{,}038\ \mathrm{W/m.K}$

7 cm white polished concrete, $\lambda = 2\ \mathrm{W/m.K}$

Rse = 0, 04 m².K / W

We therefore have:

$$R\ wall = \sum R = \sum\left(\frac{d}{\lambda}\right) + Rsi + Rse = \frac{0{,}25}{2{,}5} + \frac{0{,}15}{0{,}038} + \frac{0{,}07}{2} + 0{,}17 = 4{,}25\ \frac{m^2.K}{W}$$

And so $U\ wall = \frac{1}{R} = 0{,}24\ \frac{W}{m^2.K}$

The wall area is : *A wall = 3670 m²*

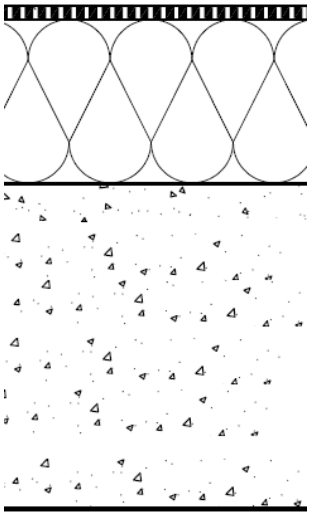
- WINDOWS

$$U\ window = 2{,}3\ \frac{W}{m^2.K}$$

The windows area is : *A window = 1605 m²*

- ROOF

Here is a roof section with its materials, with from the inside to the outside:



Picture 31 : Roof section

Rsi = 0,010 m².K / W

30cm reinforced concrete, $\lambda = 2{,}5\ \mathrm{W/m.K}$

12 cm polyuretan, $\lambda = 0{,}025\ \mathrm{W/m.K}$

1 cm asphalt tight layer, $\lambda = 0{,}03\ \mathrm{W/m.K}$

Rse = 0 m².K / W

We therefore have:

$$R\ roof = \sum R = \sum\left(\frac{d}{\lambda}\right) + Rsi + Rse = \frac{0{,}3}{2{,}5} + \frac{0{,}12}{0{,}025} + \frac{0{,}01}{0{,}03} + 0{,}10 = 5{,}35\ \frac{m^2.K}{W}$$

And so $U\ roof = \frac{1}{R} = 0{,}187\ \frac{W}{m^2.K}$

The wall area is: *A roof= 2115 m²*

- FLOOR

The bottom floor doesn't have any insulation since it will be either technical rooms or stores. The flocking (projected foam) is therefore on the ceiling of this bottom floor. We have:

Rs ceiling = 0,010 m².K / W

30cm reinforced concrete, $\lambda = 2{,}5\ \mathrm{W/m.K}$

12 cm flocking, $\lambda = 0{,}04\ \mathrm{W/m.K}$

Rs floor = 0,17 m².K / W

We therefore have:

$$R\ floor = \sum R = \sum\left(\frac{d}{\lambda}\right) + Rsi + Rse = \frac{0{,}3}{2{,}5} + \frac{0{,}12}{0{,}04} + 0{,}27 = 3{,}39\ \frac{m^2.K}{W}$$

And so $$U\ floor = \frac{1}{R} = 0{,}29\ \frac{W}{m^2.K}$$

The wall area is: *A floor= 2115 m²*

- ENVELOP U VALUE

$$Utot = \frac{3670 * 0{,}24 + 1605 * 2{,}3 + 2115 * 0{,}187 + 2115 * 0{,}29}{3670 + 1605 + 2115 + 2115}$$

$$\boldsymbol{Utot = 0{,}587\ \frac{W}{m^2.K}}$$

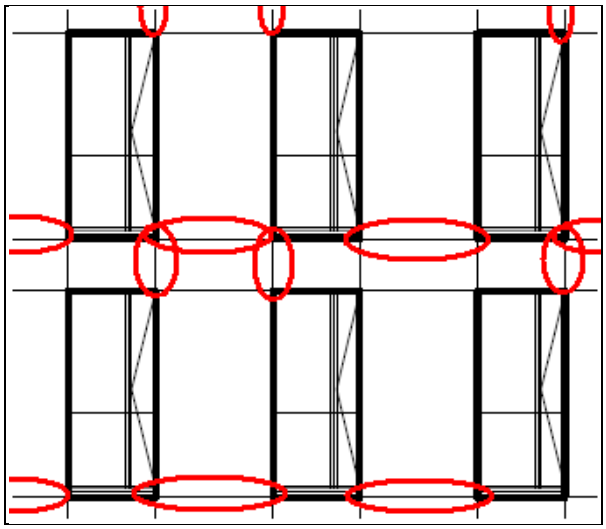
The theoretical U value was U th= 0,813 W/m².K . That means that a 35 % improvement was made between the study period and the nowadays solution. We indeed increased the wall insulation from 12 to 15cm and replaced polystyrene on the roof into polyurethane.

However, if these made that the project is more expensive now, it enabled us to enter a new building classification: “Batiment Basse Consommation “or BBC (Low Energy Demand Building). Since one of the two future buildings will be our head office, that a good way to advertise on the way we can build nowadays.

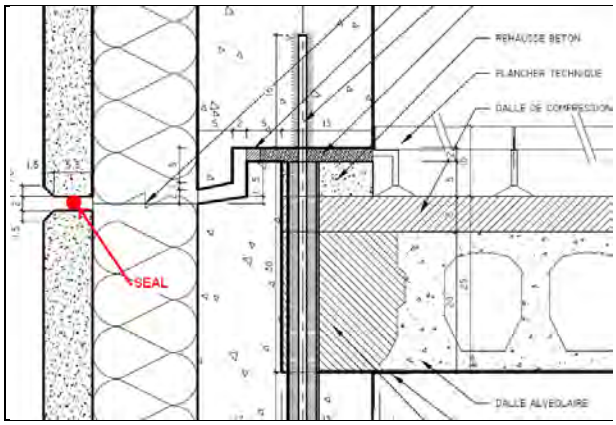
Influence of moisture in the insulation

If having the insulation outside the concrete carcass is a good way to increase the building thermal inertia and to decrease its thermal bridges, it can have some bad sides as well.

For instance, since we only hang some polished concrete prefabricated elements outside the insulation, the water tightness is not insured into this insulation. When I left at the end of my internship, the solution I presented had a bituminous seal in every single gap between the prefabricated elements.



Picture 32 : location of bitumineous seals



Picture 33 : Example of a horizontal seal

However, this has not been validated by the architect yet who could refuse it for color issues mainly, and has not been validated by my tutor who was not really keen on this seal since they sometimes fall from the gap after huge temperature variations.

The consequence could be that nothing would protect the insulation from the rainfall. However, a porous material is a poorer insulator when it is impregnated of water. Let's carry out a calculation to see from how much this could increase the heat flow at the junction between prefabricated elements

- Heat flow without moisture consideration

Without moisture issues, the heat flow through the wall just depends on the heat conductivity properties of our materials. We use the FOURRIER's law :

$$Q = -\lambda \frac{dT}{dx} = \frac{Tin - Tout}{Rwall}$$

We saw in the envelop U value calculation that for the wall we have:

$$R\ wall = \sum R = \sum \left(\frac{d}{\lambda}\right) + Rsi + Rse = 4{,}25\ \frac{m^2.K}{W}$$

Let's do the calculation for regular winter conditions in Nantes, that is to say:

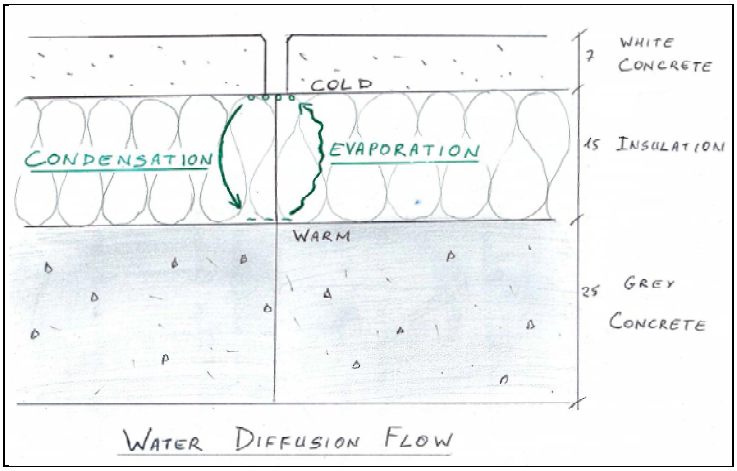
$Tin = 21°C$

$Tout = 2°C$

We then have : $Q = \frac{21-2}{4{,}25} = 4{,}47\ \frac{W}{m^2}$

- Heat flow with water diffusion

Here is a drawing explaining the process:



Picture 34 : water diffusion flow

When water comes closer to the warm surface, it evaporates while taking some heat from the indoor. When this vapor comes to the cold surface, it condensates while releasing a part of the heat it had taken indoor to the outside. Then the cycle starts again.

This extra heat flow is calculated this way:

$$Qwater = he \cdot g$$

With $he = 2500 \cdot 10^3\ J/kg$

$$g = \delta v \cdot \frac{Vs(Tin) - Vs(Tout)}{d}$$

With δv water diffusion coefficient, $\delta v\ polystyrene = 1 \cdot 10^{-6}\ m^2/s$

d : isolation thickness, $d = 0{,}15\ m$

Vs(T) mass flow of saturated vapor, $Vs(Tin) = Vs(21°C) = 18{,}32\ \frac{g}{m^3}$

$Vs(Tout) = Vs(2°C) = 5{,}55\ \frac{g}{m^3}$

We therefore have :

$$g = 1 \cdot 10^{-6} \cdot \frac{18{,}32 - 5{,}55}{0{,}15} = 8{,}5 \cdot 10^{-5}\ \frac{g}{m^2.s}$$

And the heat flow due to water diffusion is also :

$$Qwater = 2500 \cdot 8{,}5.10^{-5} = 0{,}21\ \frac{W}{m^2}$$

Conclusion:

Heat flow without water diffusion: 4,47 W/m²

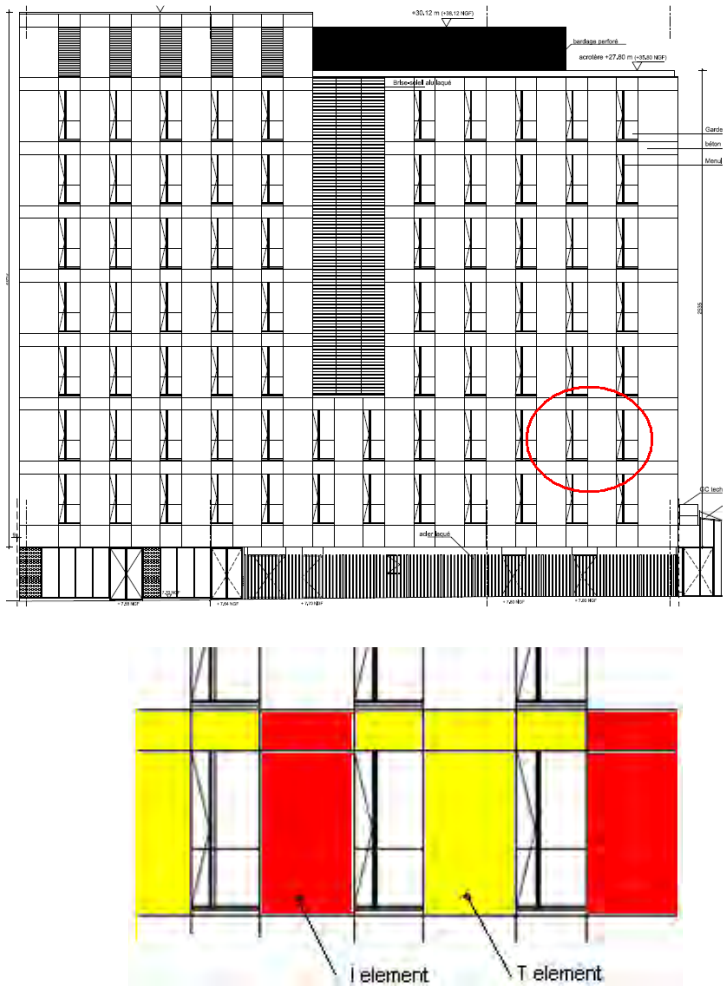
Heat flow with water diffusion: 4,47+0,21=4,68 W/m² (4,5% due to water diffusion)

We can therefore say that having a water saturated polystyrene will increase of 0,21/4,47 = 4,7 % the overall heat flow.

Design according to building physics

When we decided to use sandwich elements which weren't planned at the beginning, we realized we had to consider all the thermal issues again since it hadn't been considered by the engineering department before. My tutor gave me the mission to design the connection between elements (vertically, horizontally, near windows and roofs, at building angles…) keeping an eye on the construction process. Every time I designed something, he checked the "structural" feasibility of it and left me the thermal, air tightness and moisture consideration. In this part, I'll also present the evolution of this design which took around 4 weeks to be completely finished and to be approved by the control organism.

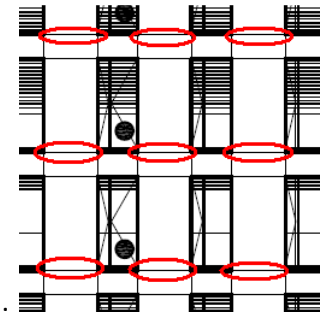
It appeared that the most cost effective solution to put in elements together was this way: "T and I shaped elements" side by side as seen on these sketches bellow:



Picture 35 : Shape of sandwich elements

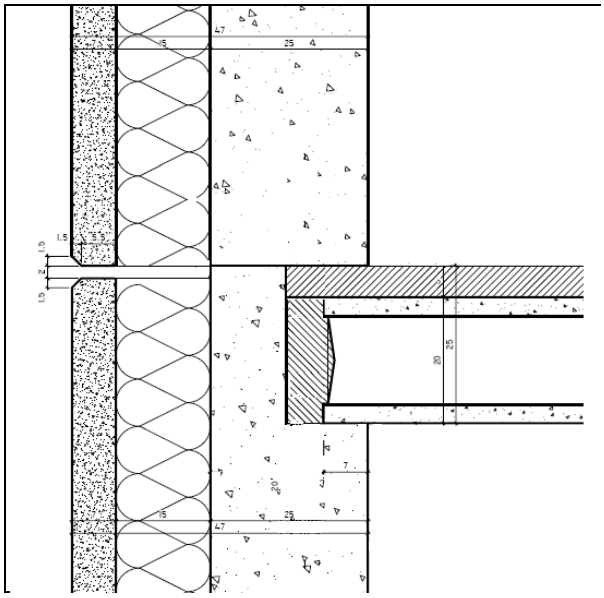
✓ Horizontal junction between elements

It took a pretty long time to design the horizontal junction since it has a big influence in the loads transmission



Picture 36 : Horizontal junctions

Without any consideration about building physics, the sketch I started with was this one:

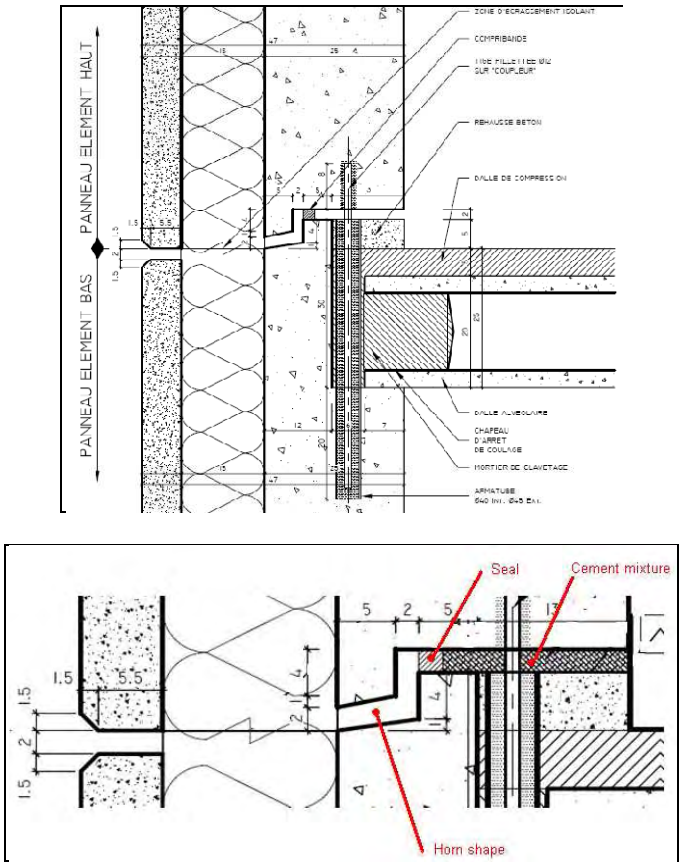


Picture 37 : Basic design of the horizontal junction

In this first sketch, no consideration was taken about moisture. We had then two possibilities: either to make it tight on the inside structural skin, either to make it tight on the thin external skin. We took the first option, considering that it would be easier to insure tightness on a wide element.

A “horn” shape was then given to the inside skin to insure water tightness, and a bituminous impregnated seal would insure the air-tightness (see following sketches).

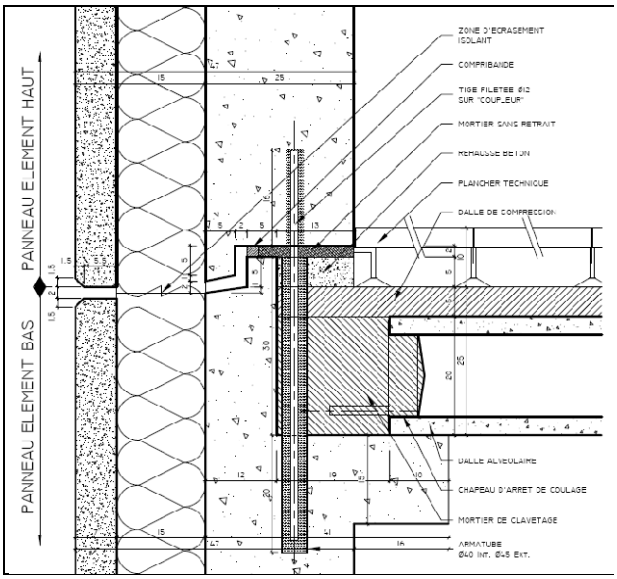
Finally, when the upper element is laid on the lower one, some cement mixture will be injected in the gap to transfer loads and to make the junction tight. This will be injected by pipes standing in the edges of the panels.



Picture 38 : Horizontal junction after a tightness study

We can notice that the insulations are compressed against each other to make the junction tighter.

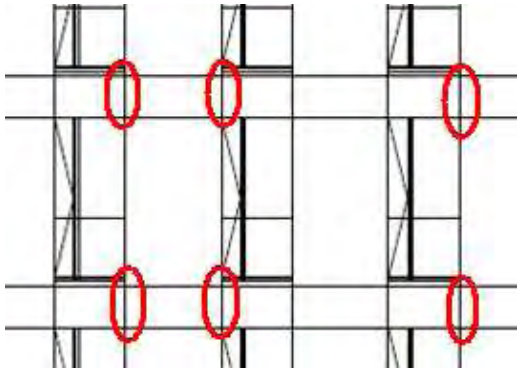
The final was approved like this by our control organism on a building physics point of view. Some changes were however brought on a structural point of view since the width of the inside skin wasn't thick enough like this to carry loads. A corbel was therefore added :



Picture 39 : Final design at horizontal junctions

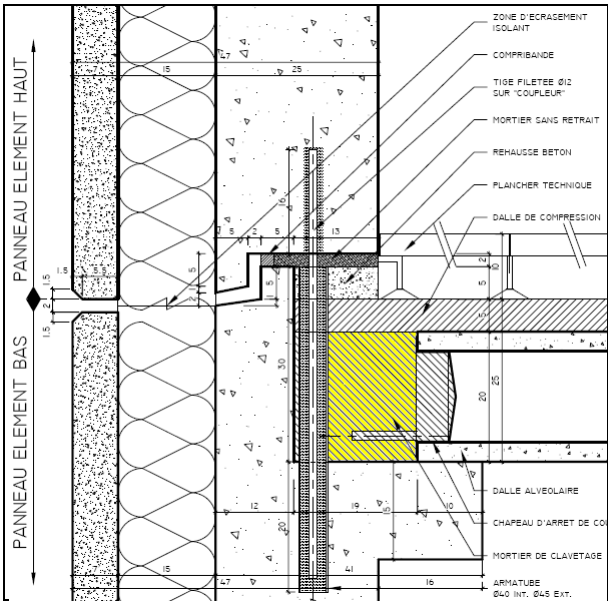
✓ Vertical junction between elements

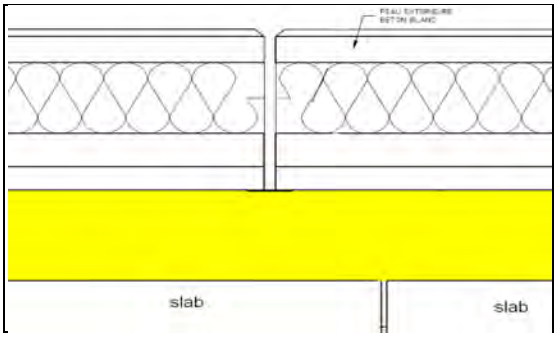
Another weak point for the façade was at the vertical junction between elements, as shown in this drawing:

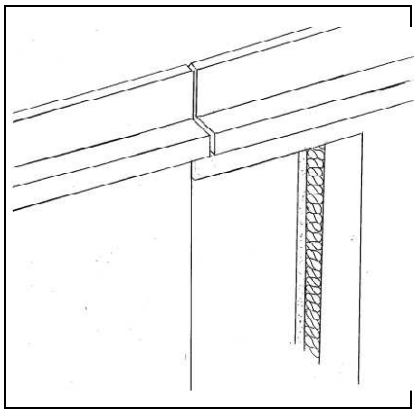


Picture 40 : vertical junctions

On a structural point of view, a concrete “beam” had to be poured on site to act as a skeleton for the building. The first sketch I design was therefore this one:





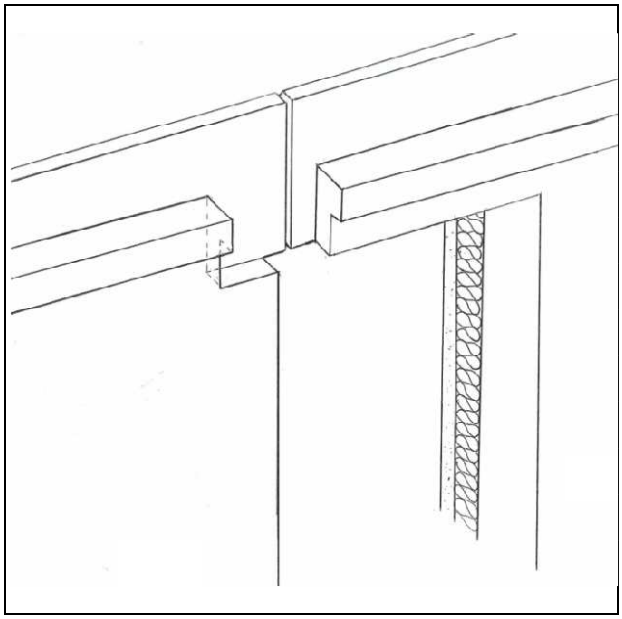


Picture 41 : structural assembling needed for the structure

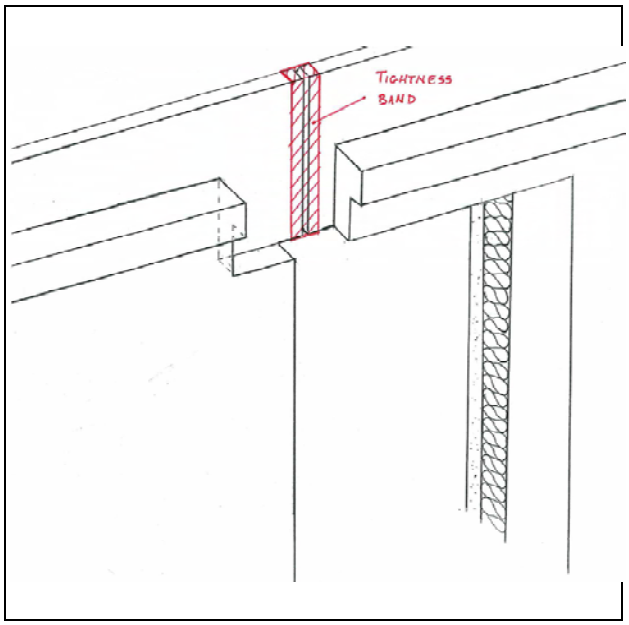
With this assembling, no tightness was insured on the whole height of the junction between panels and water could sneak into the building.

We also decided to have a assembling on the whole junction by removing a part of the prefabricated concrete to pour it on site instead. Even if we supposed these 15 cm of poured concrete were enough to insure the tightness, we added a rubber part between the two prefabricated elements and stuck some tightness band (tight bituminous tape) as well to make sure that a drop coming from above wouldn't infiltrate in the concrete.

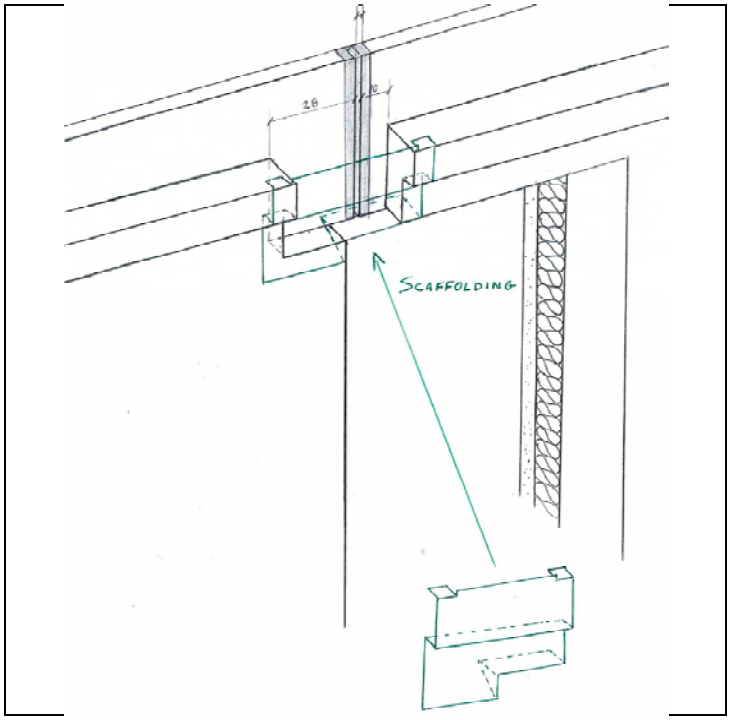
Here are the different steps of the process:



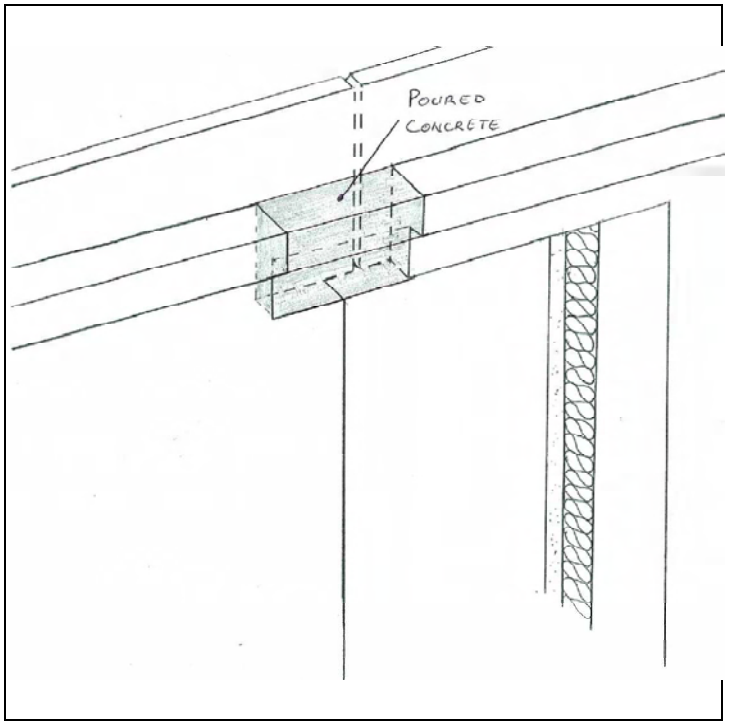
Picture 42 : Sandwich elements laid side by side



Picture 43 : Montage of the tight band

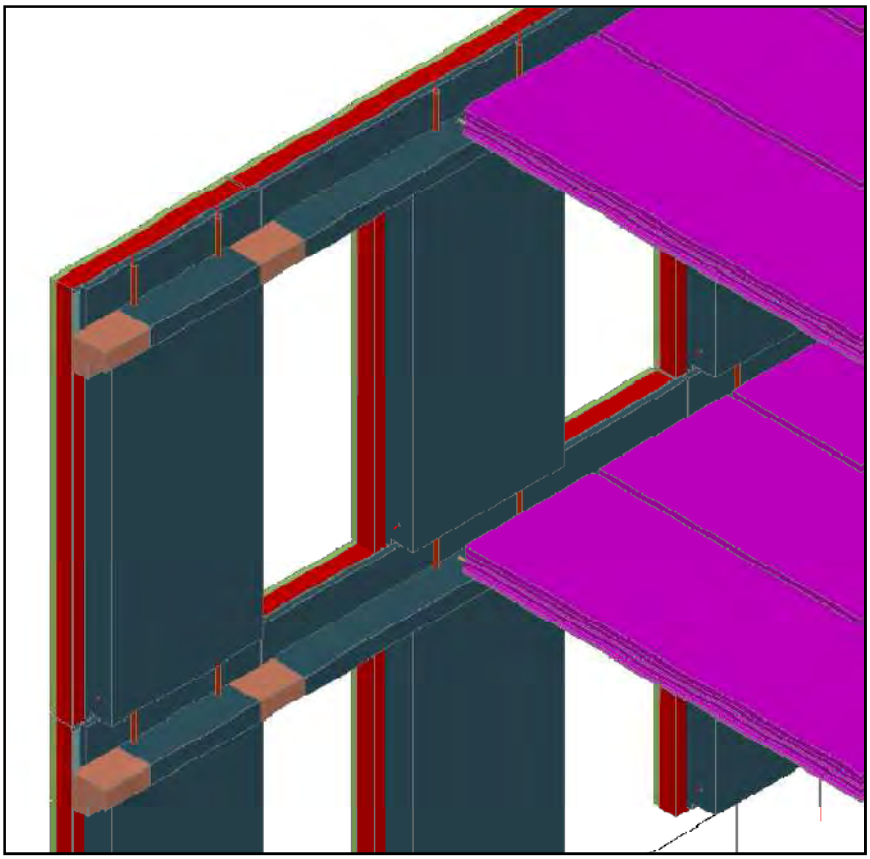


Picture 44 : Setting up of the scaffolding



Picture 45 : Pouring of concrete

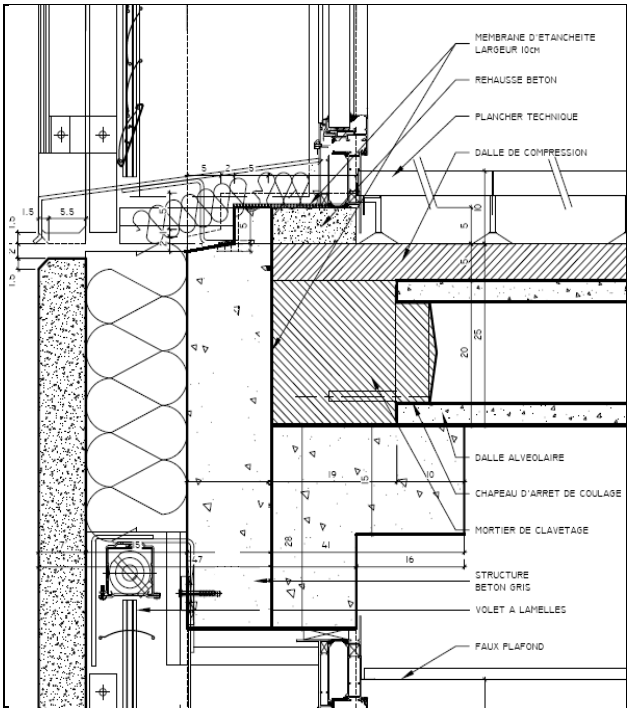
Here is a tree dimension drawing with the assembling among sandwich elements:

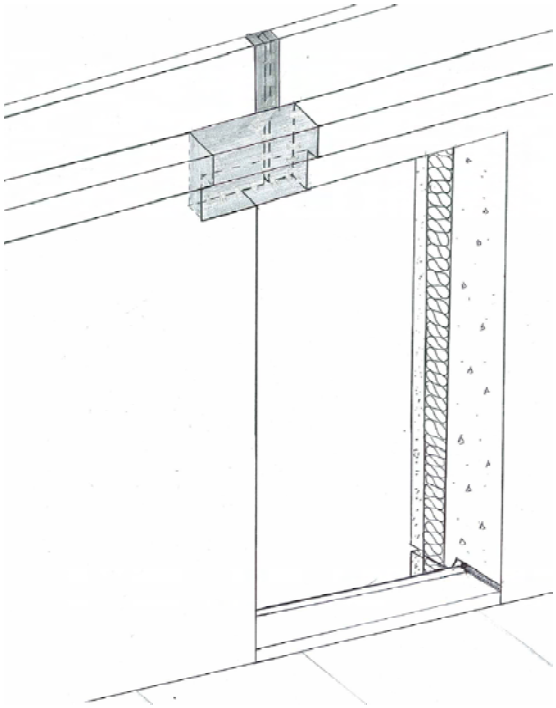


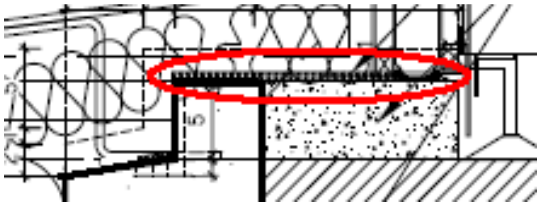
Picture 46 : Final assembling between sandwich elements

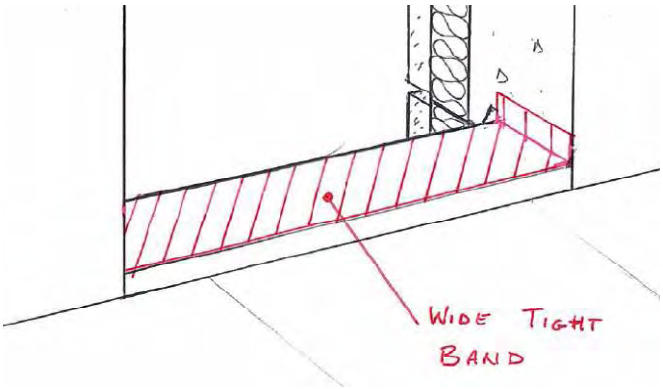
✓ Around windows

We considered the only weak point as for moisture around the window could be the underside. The only thing we made was to stick tightness band under the whole width of the window, as shown on the sketches below:





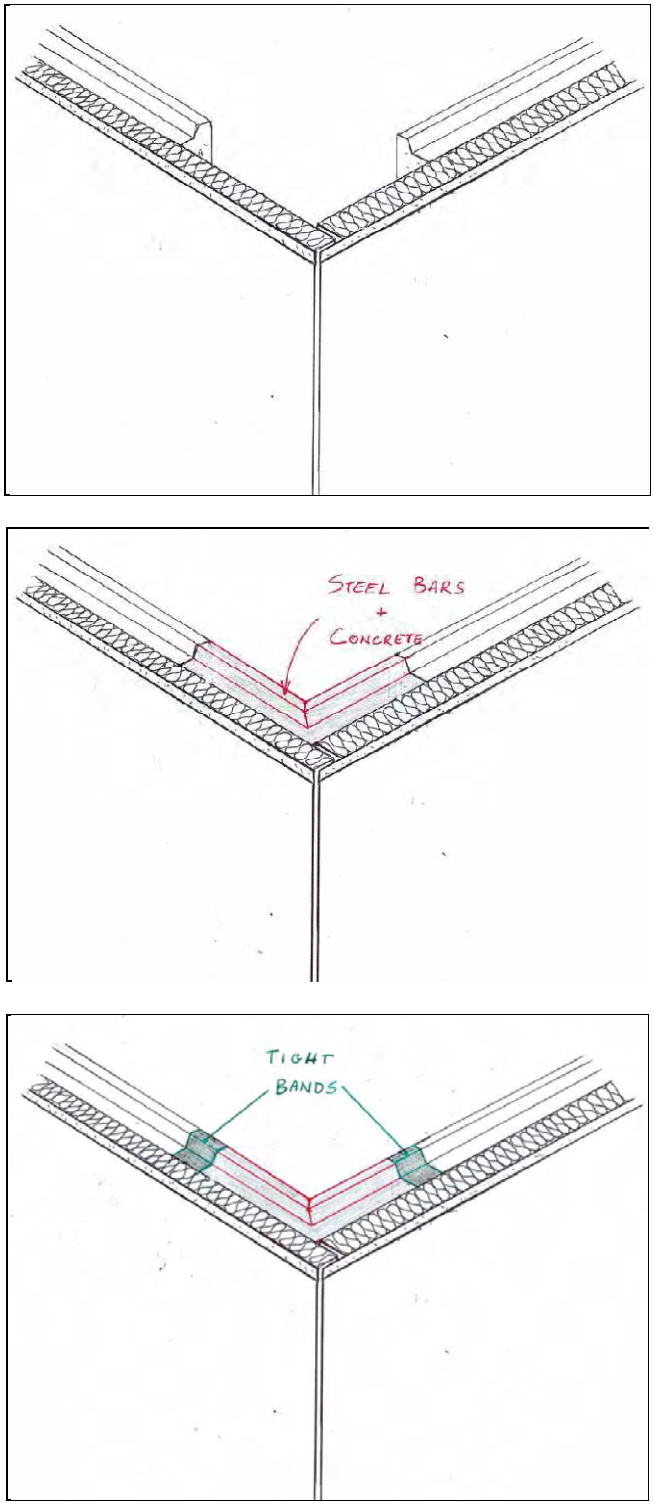




Picture 47 : Watertightness under windows

✓ Around the building angles

At every building angle, we need a gap between elements to put steel bars on site. The junction between the elements is also made on site by pouring concrete around theses angles framework. At every junction between the “on site” poured concrete and the prefabricated concrete, a tight band is is taped to avoid infiltration at the junction. Here is a drawing of an angle example.

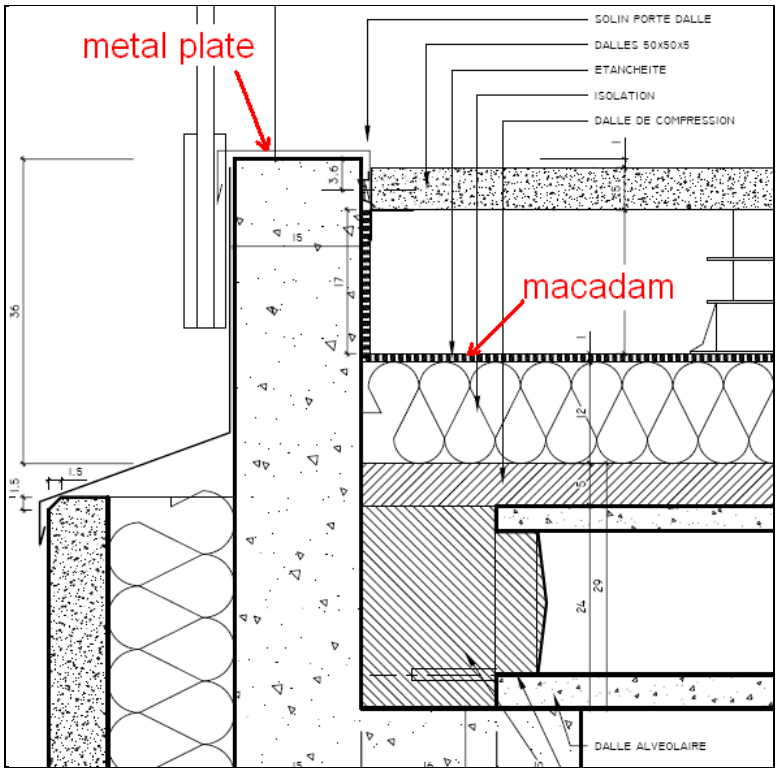


Picture 48 : Watertightness at building angles

✓ At the terrace roofing

If I didn't have to design the tightness on the terrace roofing (that will be done by a subcontractor later on), we anyway decided to draw a first solution to be able to design our concrete part according to it (especially sandwich elements at the top of façades).

The tightness on the terraces will be insured with a macadam sheet and the wall will be protected from rain by a folded metal part:

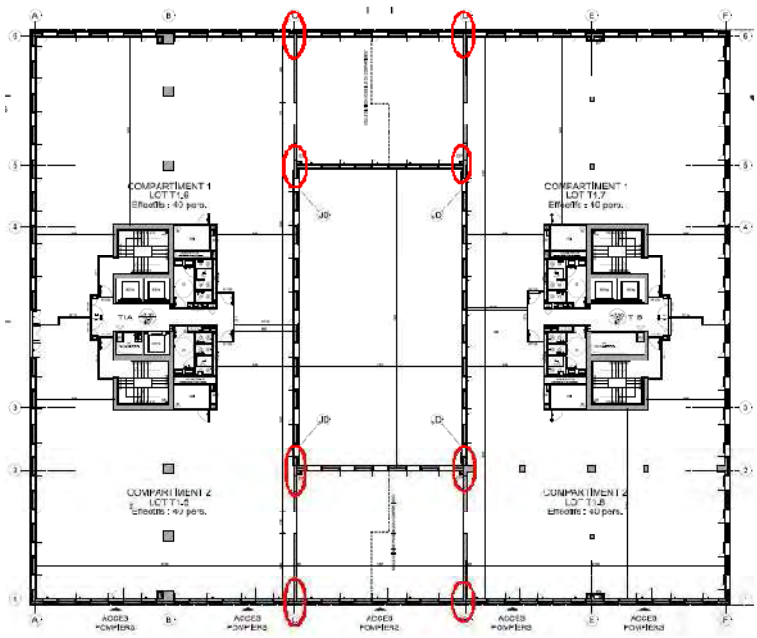


Picture 49 : Watertightness at above panels

✓ At expansion joints

Out of the two buildings being constructed, one will be longer than 30 meters.

That involves that expansion joints are needed, to enable motion between parts of this building. These are a separation in the carcass with a gap of 2-3 cm. Here is a location of these vertical expansion joints:



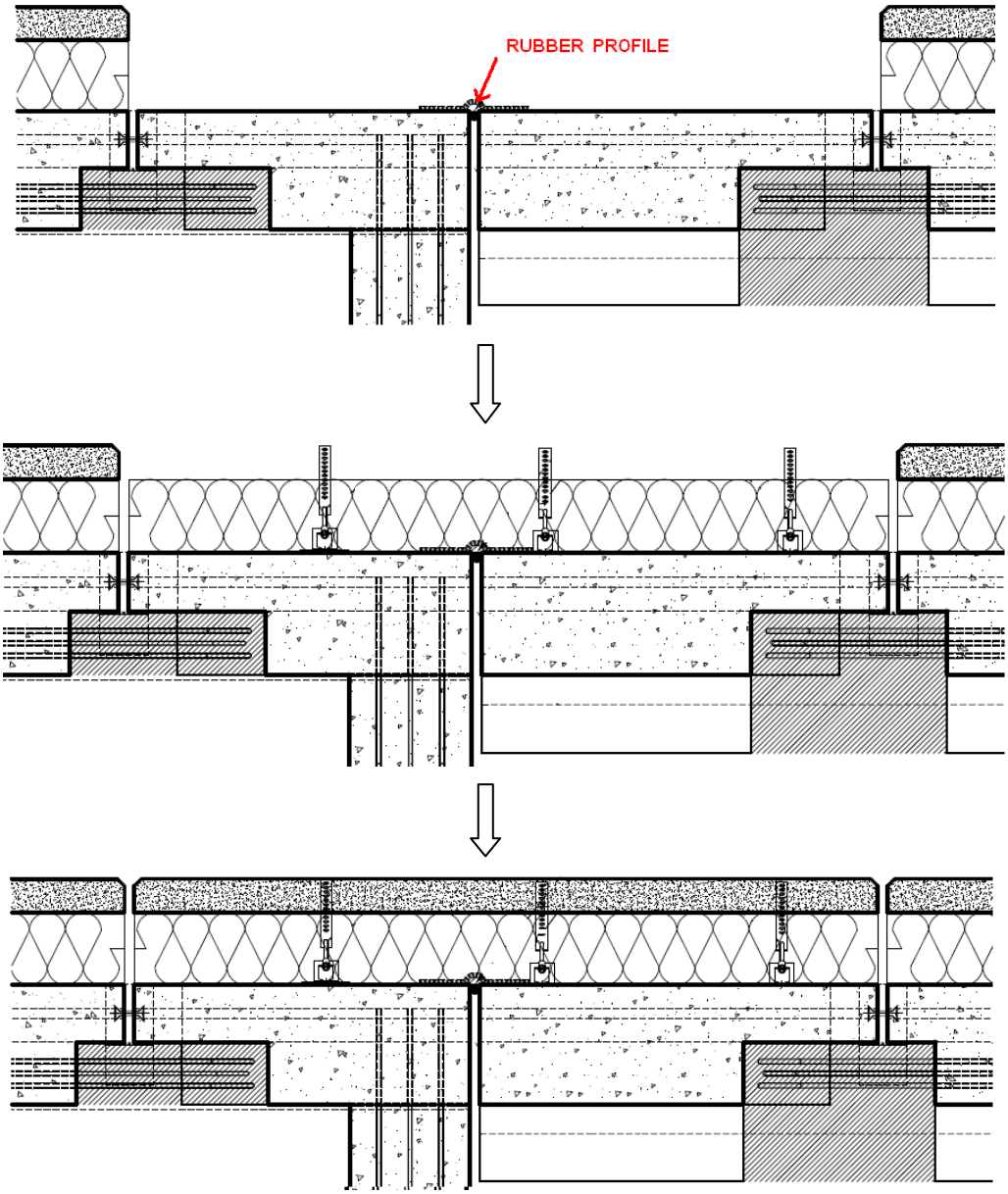
Picture 50 : Location of expansion joints

An expansion joint involves a discontinuity of the structural walls. The challenge for us was to avoid having neither a discontinuity on the white concrete (the architect wouldn't accept it) nor on the insulation.

Two scenarios appear on the building: straight façade cases and angle cases:

- <u>Straight façade cases</u>

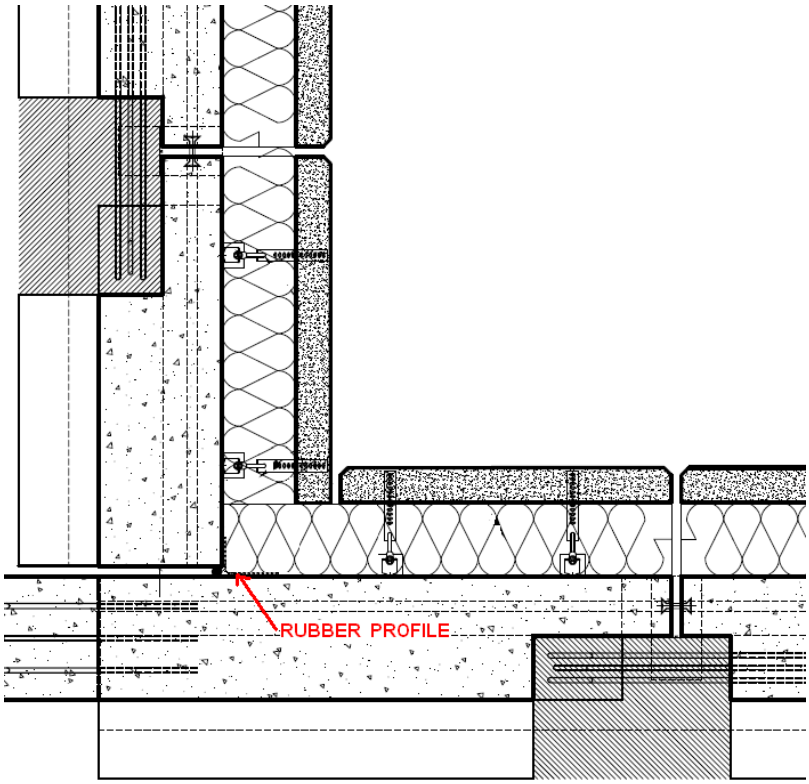
As it can be seen on the sketch below, a regular sandwich element has to be divided in two parts with a 2 cm gap in between. To have a white concrete panel in one piece, we decide to hang it on one of the two structural panels with a rail and metal parts that will carry the weight of this panel. Before hanging it, the insulation has to be added on site as well and before the white concrete. To insure a good tightness, a rubber profile is fastened between the two structural elements. Here is a description of the process:



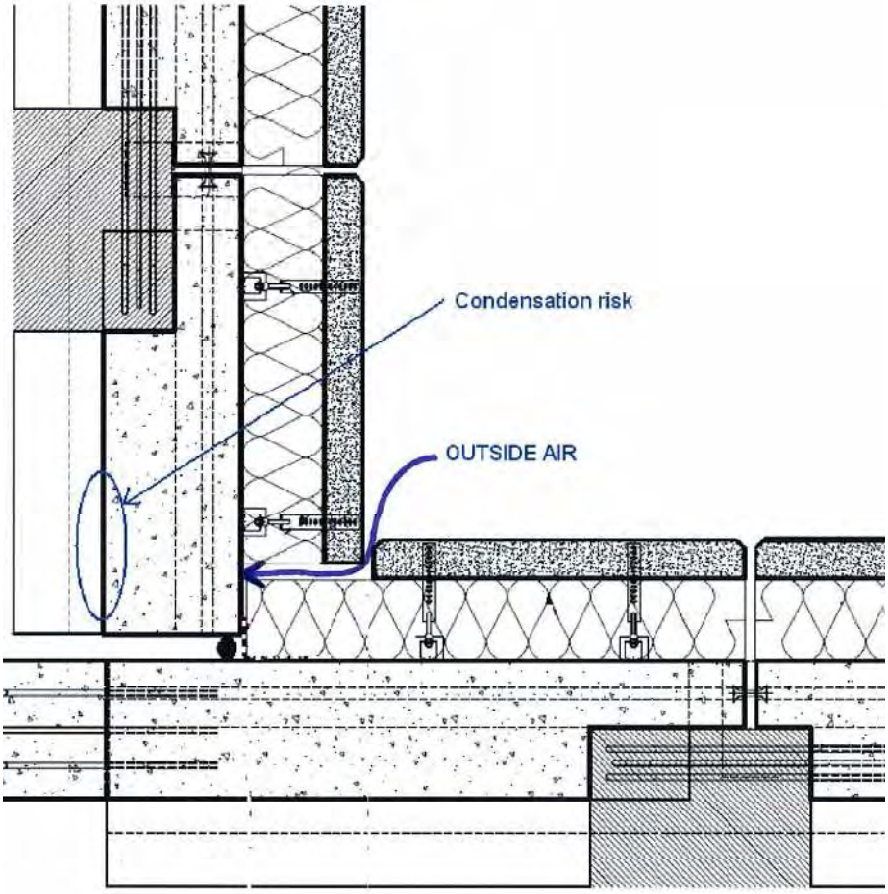
Picture 51 : Achievement of straight expansion joints

- Angles cases

We used the same technique at angles but this time the insulation of the two prefabricated elements is divided. The risk we get here is included in the notion of expansion joint itself. If the buildings move between each other, a gap can appear into the insulation as shown on the following drawings :



Picture 52 : Regular angle expansion joint



Picture 53 : Condensation risk

The problem that can occur then is during very cold temperature during winter. Indeed, id the buildings move away from each other, the gap in the insulation involve that the concrete outdoor edge is almost at the same temperature than the outside temperature. However, the concrete being by nature a rather good conductor, the temperature on its indoor edge will be rather cold as well which could create condensation problems.

Calculation

Let's carry out a simulation to see if some condensation will appear at this point:

We know that condensation will appear if:

$$Vs(Ts) > RHi \,.\, Vs(Ti)$$

Where

Vs(Ts) is the mass flow of saturated vapor in *g/m3* at the surface temperature
RHi is the indoor relative humidity
Vs(Ti) is the mass flow of saturated vapor in *g/m3* at the indoor temperature

Last winter, a temperature of -5°C last for about one week which was considered to be quiet rare for Nantes. We will also take this temperature for our study.

Since the air gap is open to the outside air, we can assume its thermal resistance is zero.

To get the concrete indoor temperature, we then use the following method:

$$Utot = \frac{1}{\sum R} = \frac{1}{0{,}13 + 0{,}04 + 0{,}25/1{,}7}$$

$$= \boldsymbol{3{,}15\ W/m^2.K}$$

With

0,13=Rsi, indoor wall surfaces air thermal resistance in m².K/W

0,04=Rse, outdoor wall surfaces air thermal resistance in m².K/W

0,25/1,7 : thermal resistance for concrete in our case in m².K/W

Heat flow :

$$Q = Utot \cdot (Tin - Tout)$$

$$= 3{,}25 \cdot (21 - (-5)) = \textbf{82 W/m²}$$

But Q is as well :

Q = (Tin – T concrete IN) / (0,13)

→ *T concrete IN = Tin – Q· (0,13)*

T concrete IN = 10,34°C

We then use tables to have the mass flow of saturated vapor for both temperature (see annex 3)

$$Vs(Ts) = Vs\,(10{,}34) = 9{,}6\ \frac{g}{m^3}$$

$$Vs(Ti) = Vs\,(21) = 18.32 \frac{g}{m^3}$$

We assume that the indoor relativ humidity is RFi = 50 %

$$and\ so \quad RFi \cdot Vs(Ti) = \mathbf{9,16} \frac{\boldsymbol{g}}{\boldsymbol{m^3}}$$

<u>Conclusion :</u>

We therfore have

$$Vs(Ts) > RHi\,.Vs(Ti)$$

That means that in the assumed conditions, some condensation would appear in front of the expansion joint on the inside of the concrete wall.

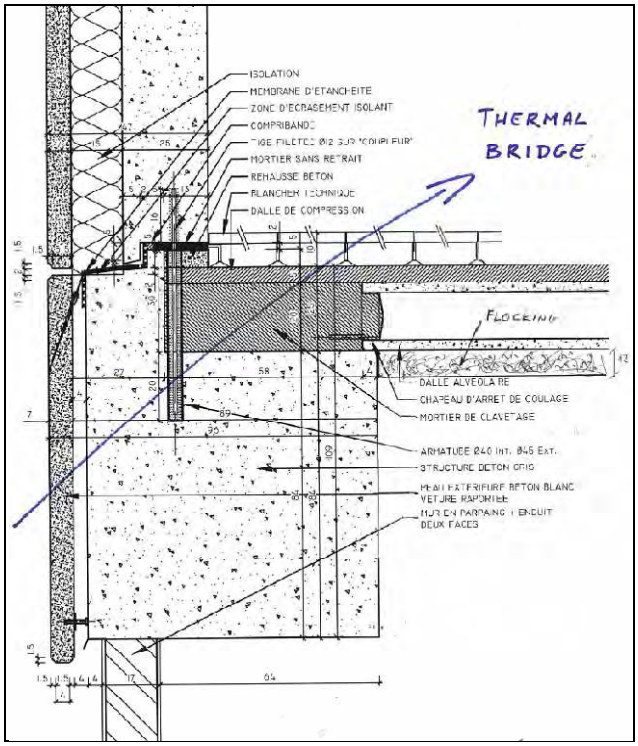
A solution to avoid this would be to put a radiator at this point on every floor which would increase the surface temperature and therefore would avoid condensation to appear.

✓ Main thermal bridges

I had of course some cases of thermal bridges during the design of these technical solutions. This showed me two things: it is really easy to avoid most of them on a building, but it showed me as well that a small part of them can't be removed and will inevitably have an influence on the thermal efficiency. Moreover, I realized that during the study process and for the future energy load calculation, thermal bridges are taken into account in a really roughly way.

- <u>Ground floor beam</u>

The bottom floor will be mainly stores with big glass facades but no sandwich elements at all. We therefore need to carry the load of the whole superstructure (from 2nd floor till bottom floor) with a large beam all around the building

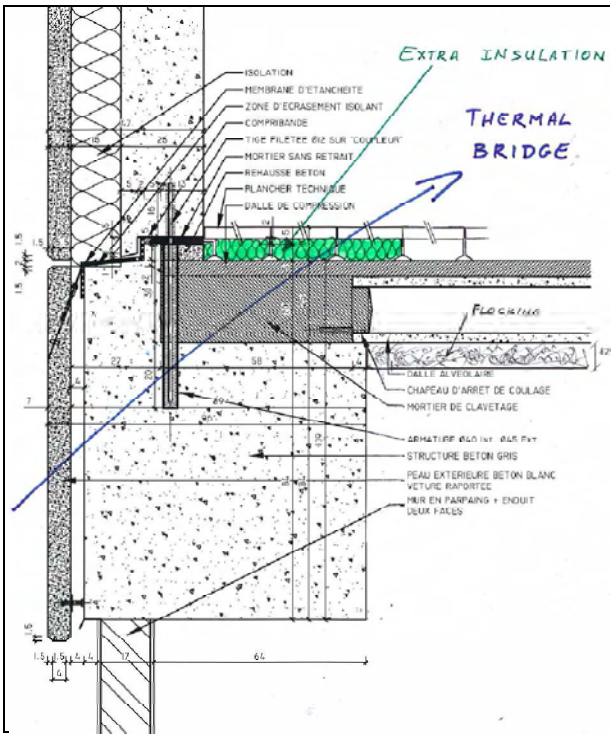


Picture 54 : Ground floor beam thermal bridge

As seen on the sketch above, no insulation is laid outside the beam and the heat from the second floor can also get out of the building trough this way.

A way I suggested to decrease this thermal bridge was to put some mineral wool on the edge of the slab, under the floor board.

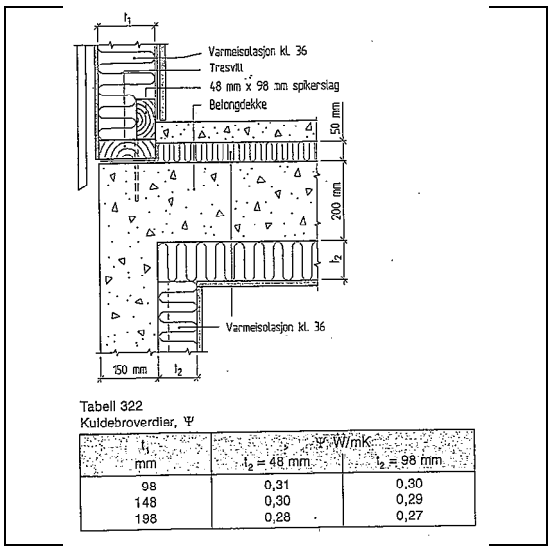
Here is a section with the extra insulation.



Picture 55 : Reduction of the thermal bridge

This solution was then accepted by the architect and the client.

To estimate the Psi value of this thermal bridge, I used a Norwegian document: *"BYGGFORSK, Kuldebroer, Tabeller med kuldebroverdier".*



Tabell 322
Kuldebroverdier, Ψ

t_1 mm	Ψ W/mK t_2 = 48 mm	t_2 = 98 mm
98	0,31	0,30
148	0,30	0,29
198	0,28	0,27

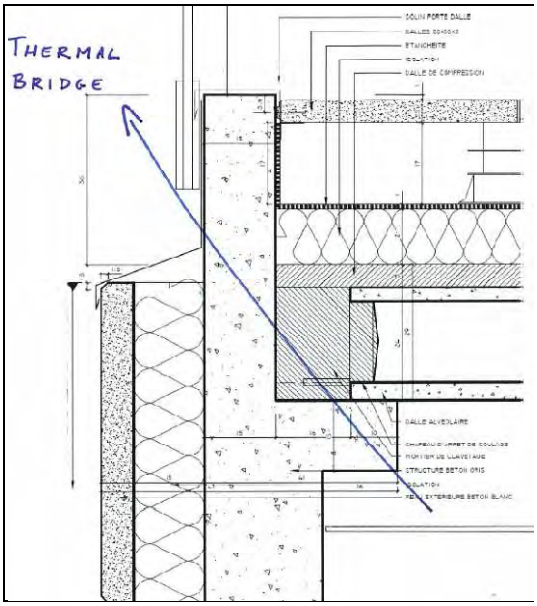
Picture 56 : Thermal bridge data

I also assumed the following Psi value for this thermal bridge :

$$\Psi\, beam = 0,3\ \frac{W}{m.K}$$

- Upper floor panels

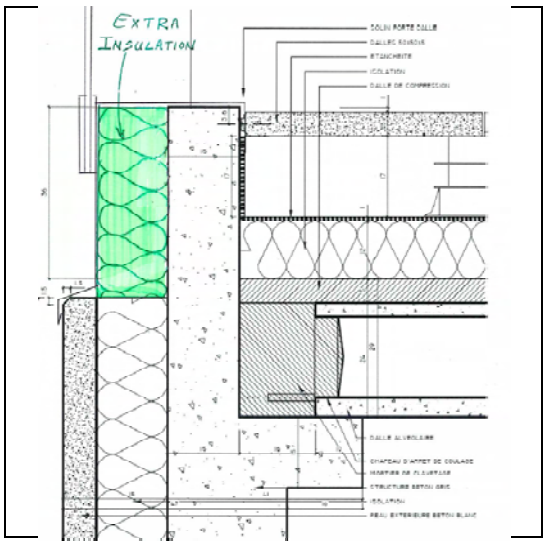
All the roof areas will be accessible and we need to increase the height of sandwich elements to be as high as the terrace upper dimension. This involve that there is no continuity between the walls insulation and the roof insulation which creates a rather big thermal bridge as shown on the sketch below:



Picture 57 : Upper floors panels thermal bridge

The first suggestion I gave was to add mineral wool in the suspended ceiling a bit like for the other case. However, it would have been much more time consuming (need to be fastened under the slab) which could have involved that the workers wouldn't have done it properly. Moreover, other workers needed this room under the slab to put wires and pipes for ventilation.

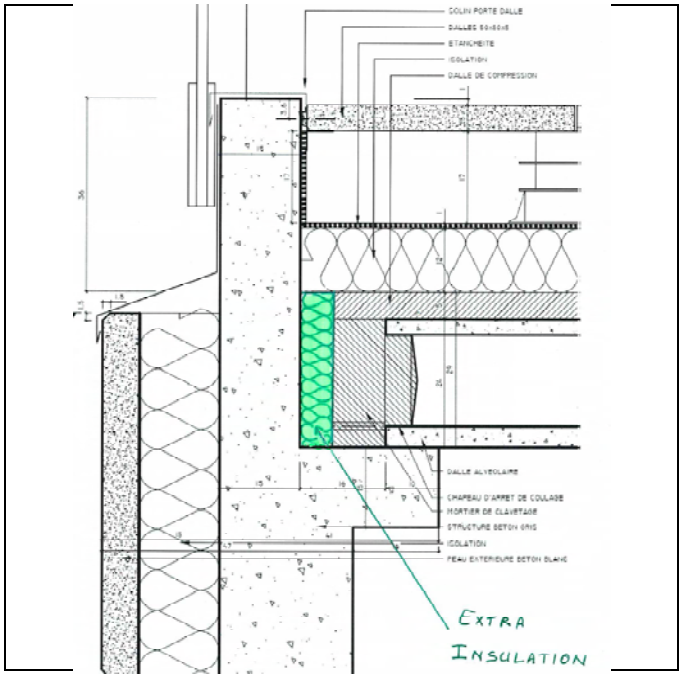
Another solution I suggested was to put an extra insulation block above the regular polystyrene. Then we just need to put a wider metal folded plate above it.



Picture 58 : First suggestion to reduce the thermal bridge

However, since these terraces are accessible we need to put a balustrade on the top of every element to prevent any fall; and the subcontractor in charge of this said us he couldn't mount his parts on such a wide plate.

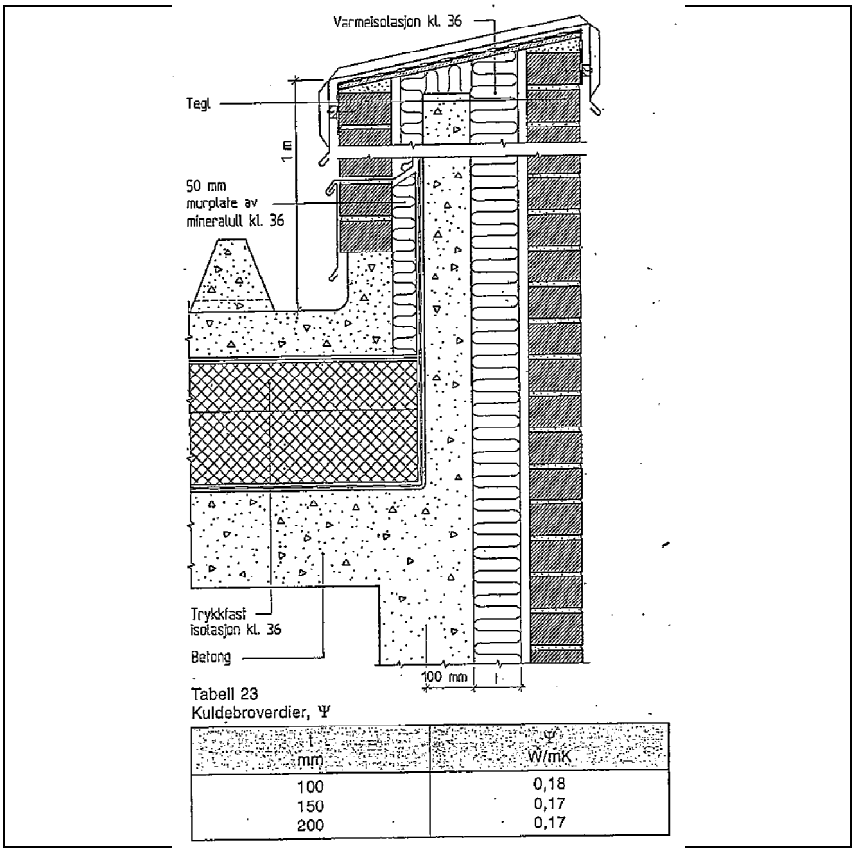
Therefore, we presented recently another solution which is to put a standing polystyrene plate against the sandwich element itself. Even if the thermal bridge is still there afterwards, that's a simple way to reduce it:



Picture 59 : Final suggestion to reduce the thermal bridge

Before presenting this solution to the architect and to the client, I need an agreement from the engineering department. This extra insulation will indeed decrease the width of the concrete volume poured on site which could be a problem for the good covering of the framework inside.

To estimate the Psi value of this thermal bridge, I again used a Norwegian document: *"BYGGFORSK, Kuldebroer, Tabeller med kuldebroverdier".*



Tabell 23
Kuldebroverdier, Ψ

L mm	Ψ W/mK
100	0,18
150	0,17
200	0,17

Picture 60 : Thermal bridge data

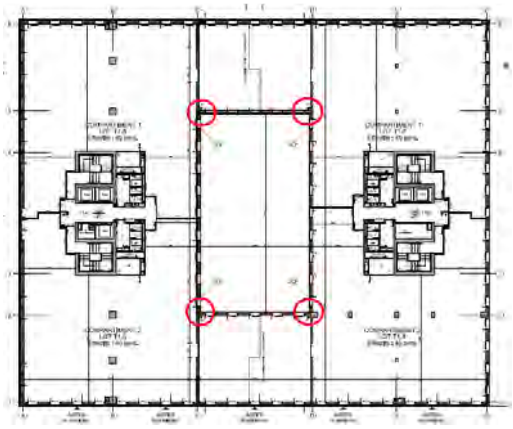
Our case in worth than this data case since we have no insulation of the top of the concrete.

I also assumed the following Psi value for this thermal bridge:

$$\Psi\ upper\ panel = 0,20\ \frac{W}{m.K}$$

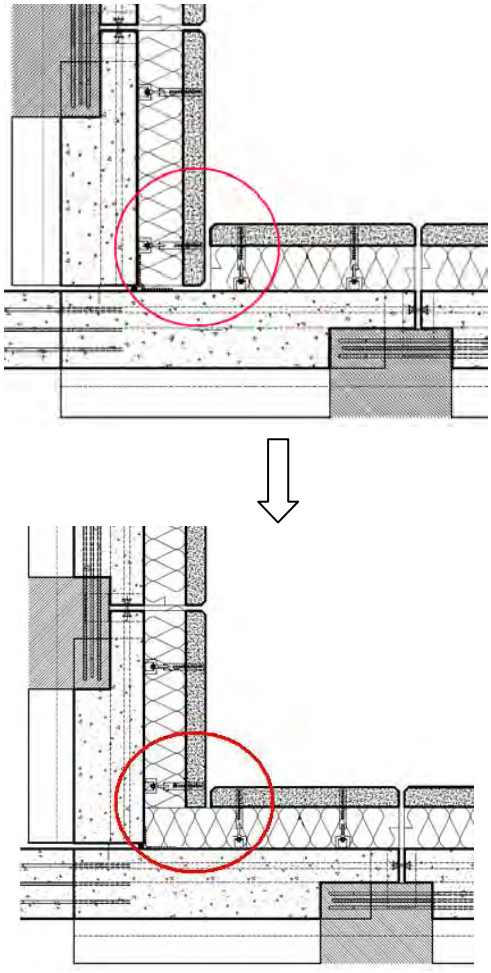
- Re-entring angles

There will be a patio in the middle of the biggest of the two constructed buildings. That involves that there will be four re-entring angles at every floor:



Picture 61 : Re-entring angles localization

On the original architect sketches, the white concrete prefabricated plates were designed in a way that a thermal bridge is created. A simple solution accepted by the client was to reduce a bit the length of one of the white concrete plate as shown on the sketches below:

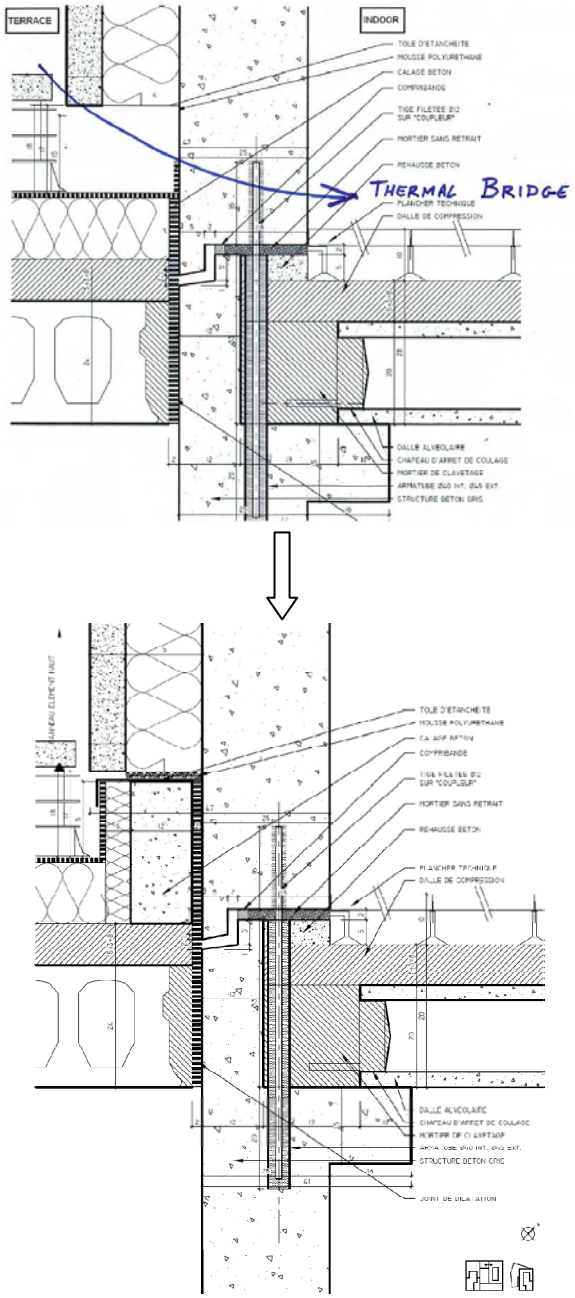


Picture 62 : Suppression of a thermal bridge on re-entring angles

- Terrace panels

Some parts of the building will be lower than others. We therefore have some roofing terrace with sandwich elements on their edge. First, no insulation was prescribed at the junction between the terrace and the wall as shown on the sketch below

We considered of course that a continuity of the insulation had to be done and added a polystyrene bloc at this point. Here is a good example of a thermal bridge easy to get rid of. The polystyrene will be a 5 to 10 mm thick XPS, to be able to resist to water contact on a long term.

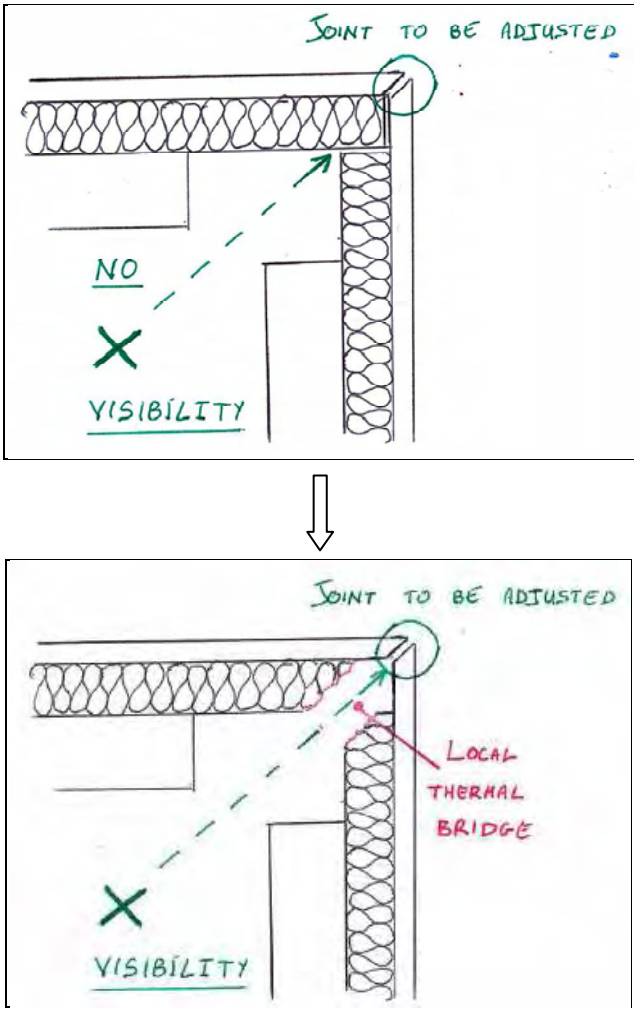


Picture 63 : Reduction of a thermal bridge on roofing terraces

In this part, we will point some mistakes that could be done during the construction process which would have an influence on the future thermal efficiency of the building. I saw some of them on the building site already; others occurred during others construction sites of our sandwich elements prefabricator.

✓ Angles:

As we could see during the laying of the prototype sandwich elements (see introduction), it was no problem to line two regular elements up together. It was much harder to manage to put angles elements together since from the inside we can't see the joint between them. The reaction our workers had was then to make a hole in the insulation to be able to see the two edges and to set up them correctly:



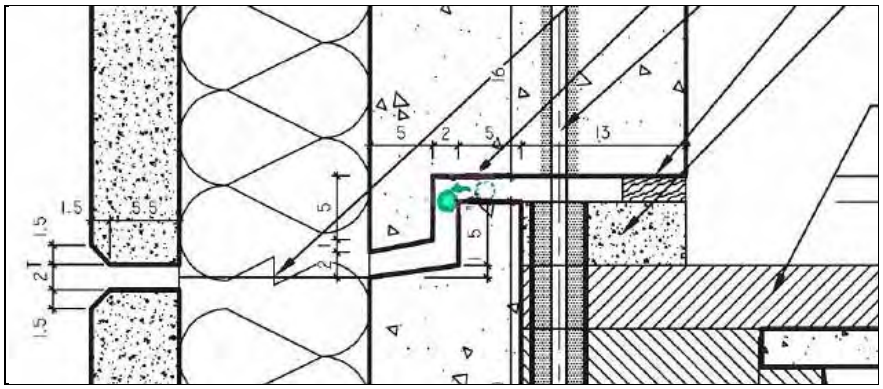
Picture 64 : Local deterioration of the insulation by workers

The consequence is that it creates some small thermal bridges at every angle

Solution: Just before leaving my position, I produced a short paper about how to solve this problem. I think the best solution is not to put the whole insulation in the prefabricated element. A polystyrene block could be indeed added from above when the two elements are settled, which could enable workers to see the joint during the laying.

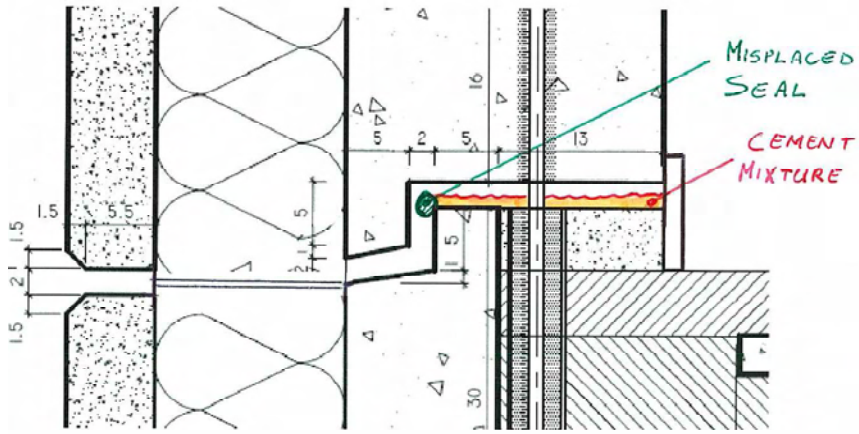
✓ Bituminous seals

The air and water tightness at horizontal junctions between elements will be done thanks to a cement mixture which will fill the gap between the elements. To avoid this cement to get into the gap and then to leak on the insulation during its pouring, a compressed bituminous seal is laid This seal is stuck on the lower element and is getting compressed when the higher one is laid. However, the is a risk when the higher element is laid with the crane to unstIck the seal so that it slides on the vertical part as shown on the drawing below.



Picture 65 : seal sliding during crane handling

It is very hard to see if this seal is at its right location in the middle of the panel, since the fact it slipped doesn't mean the cement mixture will leak. Such a case could be this one:



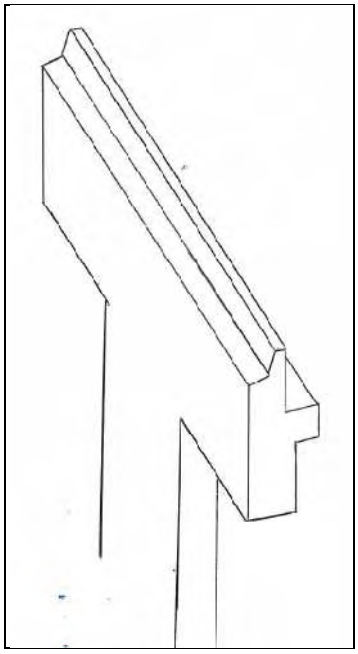
Picture 66 : Example of a air tightness fault

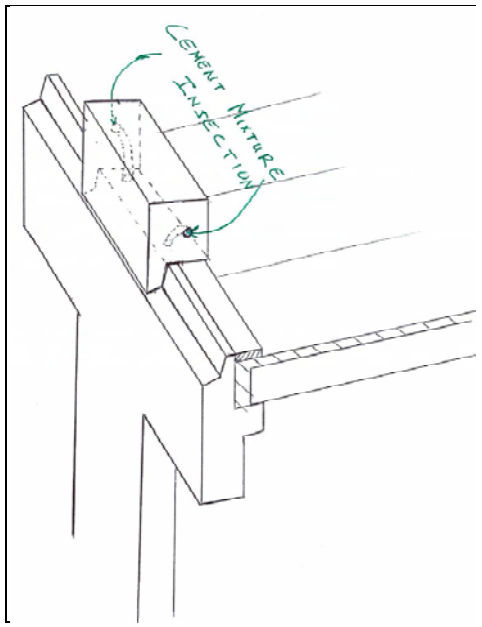
In this case, there is still an air gap and the tightness is not insured. The consequences could be that it creates an air flow through this gap, which could be a problem when there is a high relative humidity in the outside air.

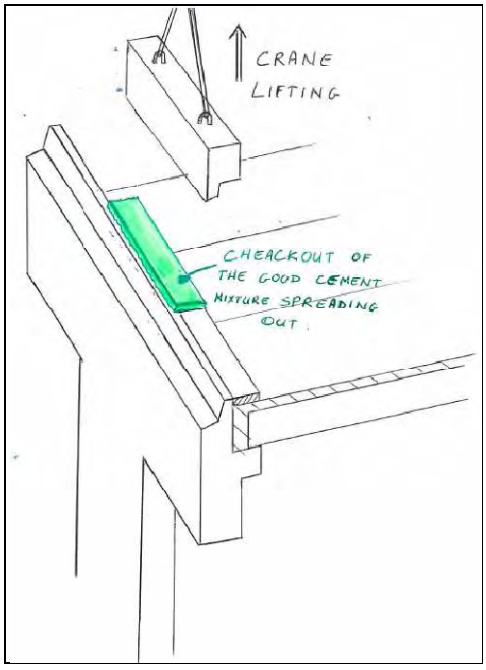
Solution: The only thing I could suggest was to be really careful during the cement mixture pouring process. Indeed, if we can be sure the whole gap is full of this mixture, no air gap will remain. If the seal is not properly located, then a cement mixture leakage will appear during its pouring, meaning than we need to make it tighter by adding an extra silicone seal from the inside for instance.

Moreover, to be sure our process was reliable; we decided to do a test on our prototype building. It consists in adding an extra element on the top of the presented panels, to pour the cement mixture and then to come the day after and to pull on this extra element with the crane to check if the tightness was really done.

Here are the different stages of the planned test:





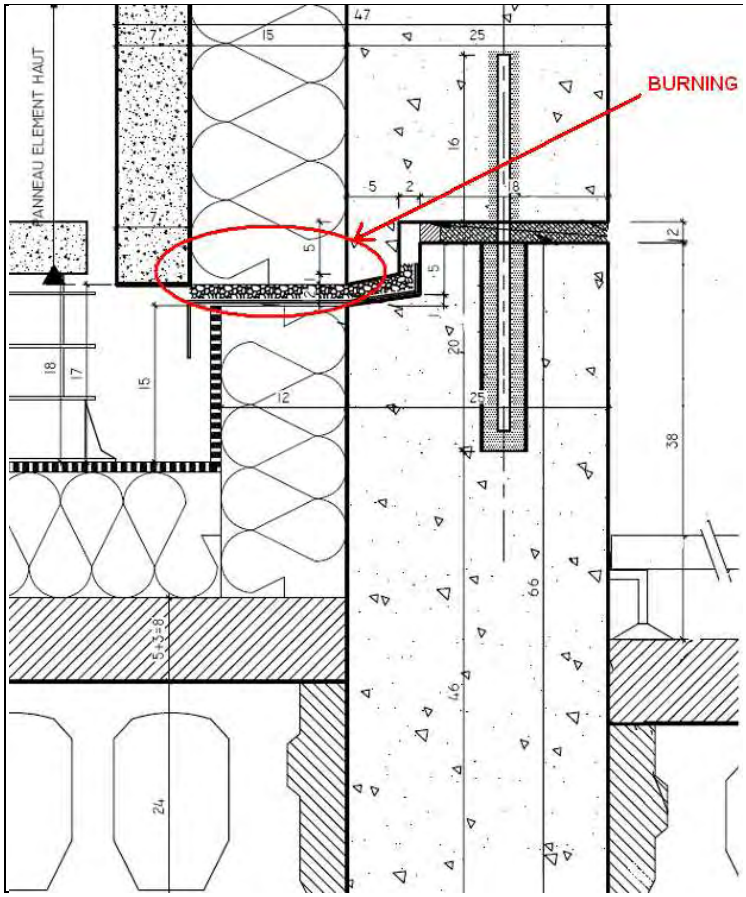


Picture 67 : Checkout of the air tightness bewteen elements

✓ Protection on terraces

On every terrace an asphalt based mixture will be put on to insure a good water protection. This kind of product has to be melted on site with a blowtorch to be position. The risk is then for the sandwich elements on the edge of these terraces, whose polystyrene is not protected in its lower part against a potential contact with the blowtorch flame.

The consequence of such thing will be again a discontinuity in the insulation involving a thermal bridge.



Picture 68 : Sensitive area during water tightness achievement

Solution: A solution could have been to integrate a protection for the insulation when the element is prefabricated as a metal plate for instance. However, we it was an extra cost that we couldn't afford. We will therefore just control the workers on site so that they pay attention when they get closer to the façades.

Heating demand

During the study period, a heating demand estimation was made. We will try in this part to carry the same calculation with the degree hour method and with taking into account the main thermal bridges.

The heating demand is calculated with the following formula:

$$E = Qtot \cdot Gt$$

- Calculation of the specific heat losses Qtot :

The building's heat losses are a combination of transmission losses (including thermal bridges) and ventilation losses:

$$Qtot = Qt + Qv$$

- TRANSMISSION LOSSES

$$Qt = \sum Ui \cdot Ai + \sum \Psi j \cdot Lj$$

$\sum Ui \cdot Ai = 5581\ W/°C$ as seen during the calculation of the envelop U value

$\sum \Psi j \cdot Lj$ We will take into account the two main thermal bridges we took into account during the study, that is to say:

Upper sandwich elements (p49)

$\Psi \approx 0{,}20$

L = 380 meters

Bottom floor beam (p45)

$\Psi \approx 0{,}3$

L = 380 meters

We therefore have:

$$Qt = \sum Ui \cdot Ai + \sum \Psi j \cdot Lj = 5581 + 0{,}20 \cdot 380 + 0{,}3 \cdot 380 = \mathbf{5771}\ \frac{\boldsymbol{W}}{\boldsymbol{°C}}$$

- VENTILATION LOSSES

$$Qv = \rho \cdot c \cdot q\ vent \cdot (1 - v) \cdot d + \rho \cdot c \cdot qleak$$

The total ventilation flow for the building is $q\ vent = 3{,}8\ \frac{m^3}{s}$

We assume that we have no leakage on the building, so $q\ leak = 0\ \frac{m^3}{s}$

The regeneration factor for the building is 75 %, and the heat exchanger works on full time (d=1)

We have therefore:

$$Qv = 1200 \cdot 3{,}8 \cdot (1 - 0{,}75) \cdot 1 + 1200 \cdot 0 = \mathbf{1140}\ \frac{\boldsymbol{W}}{\boldsymbol{^\circ C}}$$

And so :

$$Qtot = Qt + Qv = \mathbf{6911}\ \frac{\boldsymbol{W}}{\boldsymbol{^\circ C}}$$

- Calculation of the degree hour factor Gt:

To get this factor, we need to estimate the "free heat" we will get thanks to the building activity (people, computers…). I could find some data ("Energi och ByggnadsDesign", Helena Bülow-Hübe) recommending 4 W/m² of free heat production for offices buildings.

We have 13 500 m² of offices, so $Pfree = 13500 \cdot 4 = 54000\ W$

The degree hour Gt depends on the balance temperature, and the yearly average temperature.

T year_average = 13,2°C for Nantes

This balance temperature is the outdoor temperature when the heating season of the building starts.

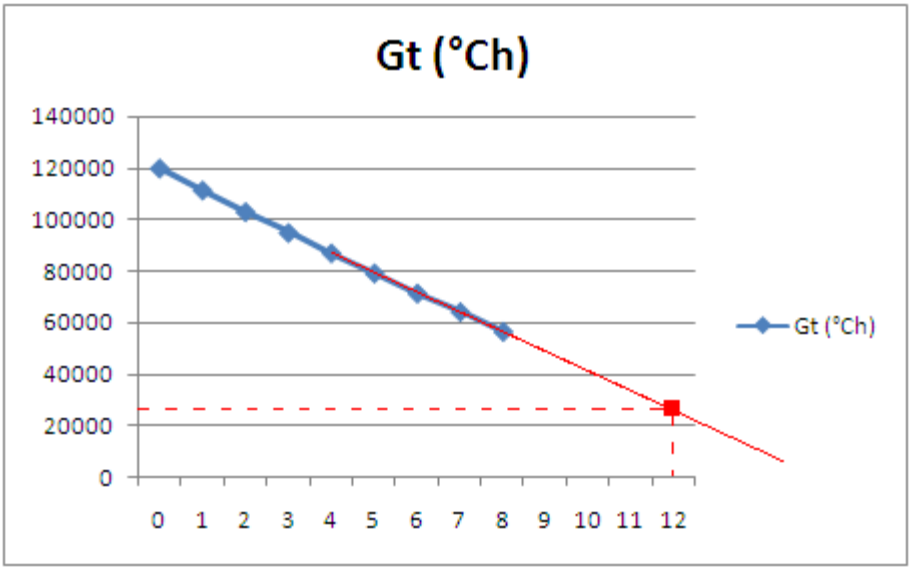
$$Tb = Tin - \frac{Pfree}{Qtot}$$

$$Tb = 21 - \frac{54000}{6911} = 13{,}2°C$$

For a 13,2°C balance temperature, we have the following values for Gt :

Gt (°Ch)	120000	111500	103100	95000	87100	79300	71500	64300	56600				?
T o_av (°C)	0	1	2	3	4	5	6	7	8	9	10	11	12

Since I had no values of Gt for a higher temperature than 8°C, I had to extrapolate to get the value for 12°C (the year average temperature in Nantes).



Picture 69 : Degree hour graphics

With this method, we can read that the Degree Hour value is around 26 000 °C.h

We can now calculate the total heat demand over a year :

$$E = Qtot \cdot Gt = 6900 \cdot 2600 = 17{,}94 MWh, year$$

It is a rather low value, which can be explained by a Balance temperature close to the year average temperature and thanks to a good regeneration coefficient as well. To have a more accurate result, a detailed calculation of free heat should be done has well.

Thanks and conclusion

I first would like to thank Jesper ARFVIDSSON who agreed to be my tutor for this Master's Thesis and who enabled me to do this internship in France. I would like to thank my company tutors Nicolas COURTOIS and David LE BIGOT who helped me in my improvement as a site manager.

On a personal point of view, I am really satisfied having been able to apply the knowledge I received during my education at LTH to this internship on a building site. It showed me that France is improving its attitude regarding energy efficient buildings and that people are now aware they should reduce energy loads in buildings.

However, this internship showed me a long work stills remains to change main of the workers mentalities so that they will think that avoiding a thermal bridge is as important as working secure or respecting the deadline.

I realized indeed that it can be hard and expensive to increase from 5% the energy efficiency of a building, but really easy and fast to decrease it from 5 % if the job isn't done properly on site.

One last word about my double degree in LTH. I would like to thank teachers like Birgitta Nordguist , Lars-Erik Harderup, Björn Karlsson and Helena Bülow-Hübe who accepted me in their courses. The education I received in these courses was not offered in my home university and I got a real advantage compared to students who stayed there.

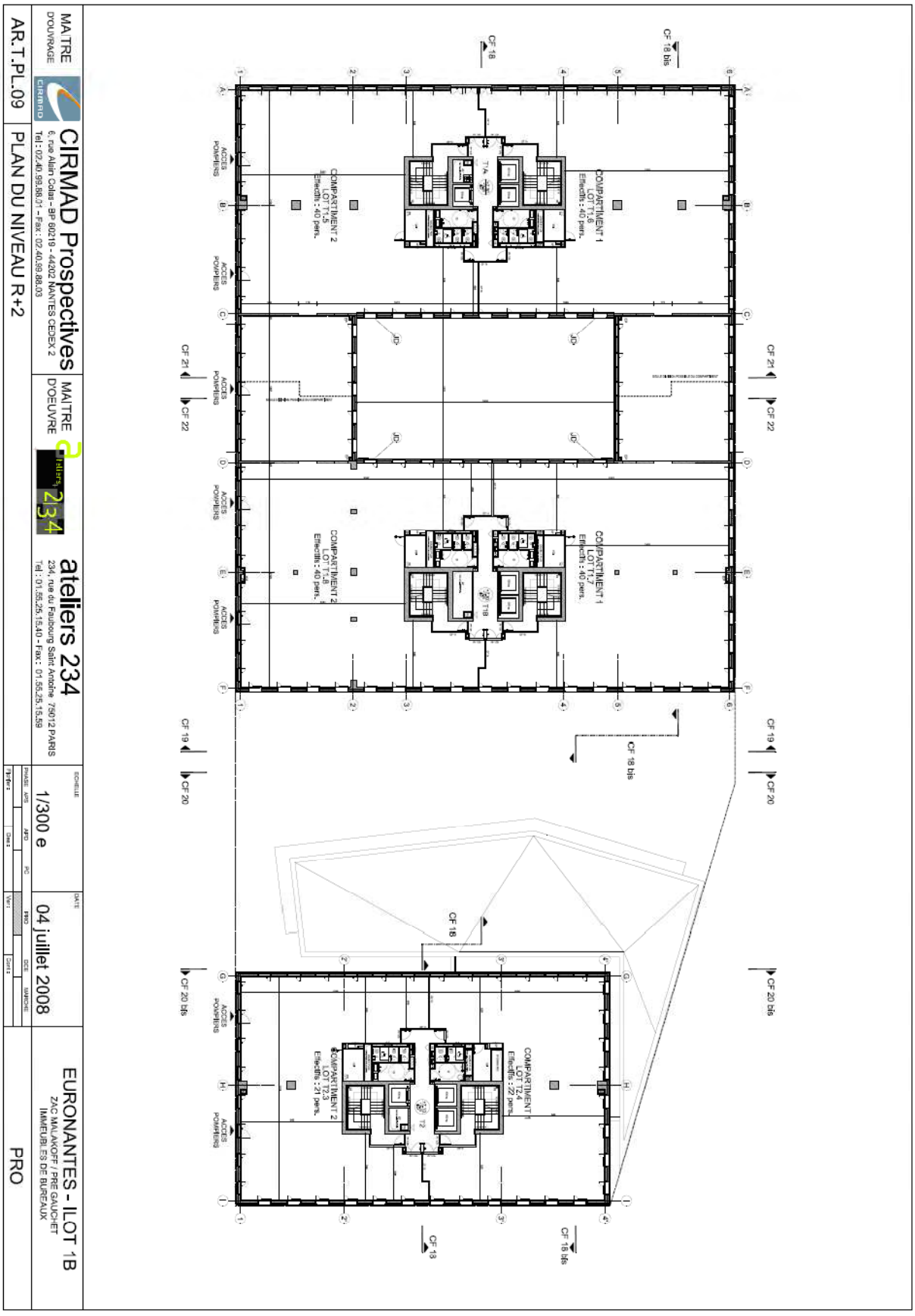
ANNEXES

Annex 1 : Sketch of a regular superstructure floor

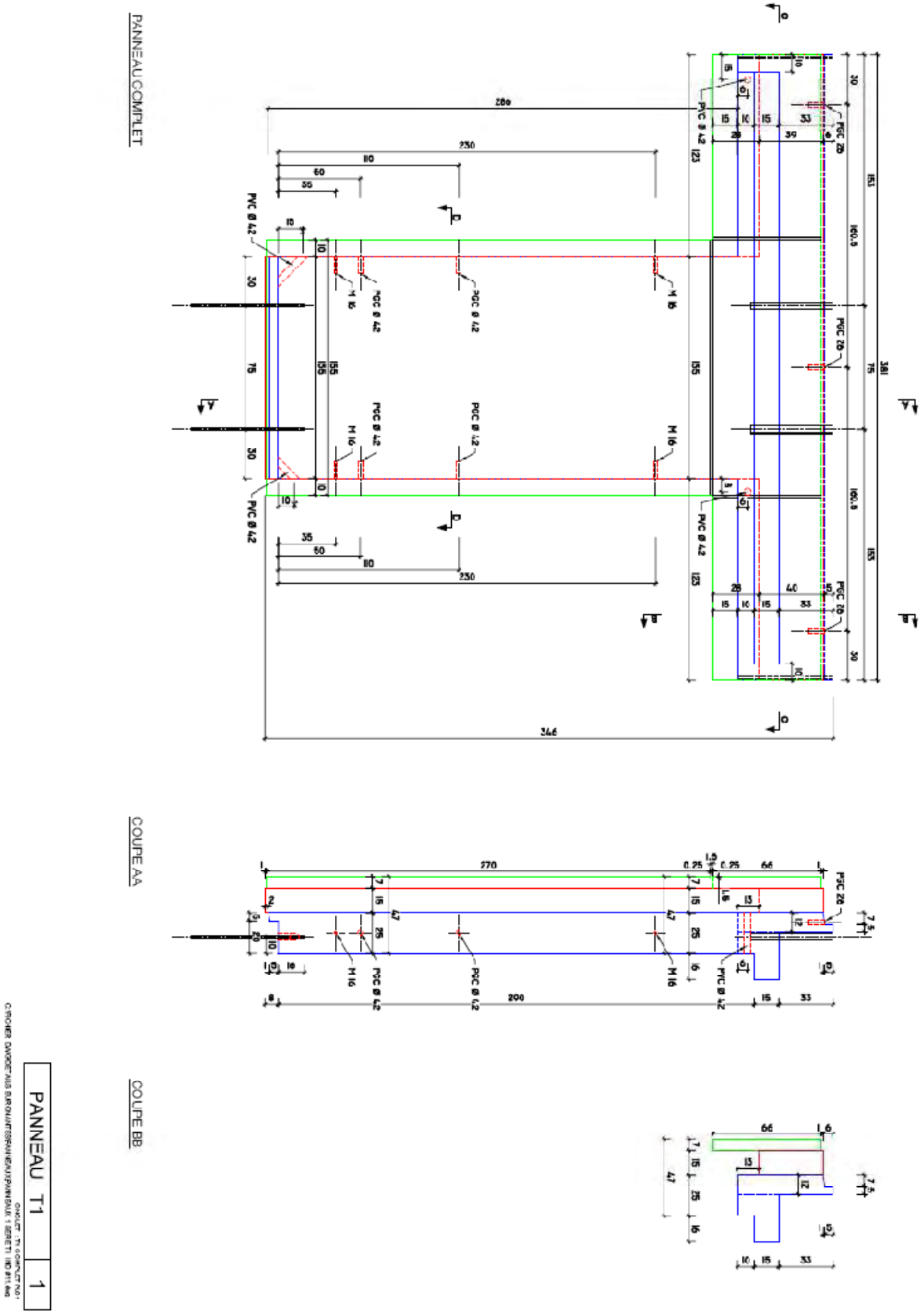
Annex 2 : Example of a manufacturing panel sketch

Annex 3 : Table of mass flows of saturated vapor

Annex 4 : Sketch of the prototype building



Annex 1 : Sketch of the 3rd floor

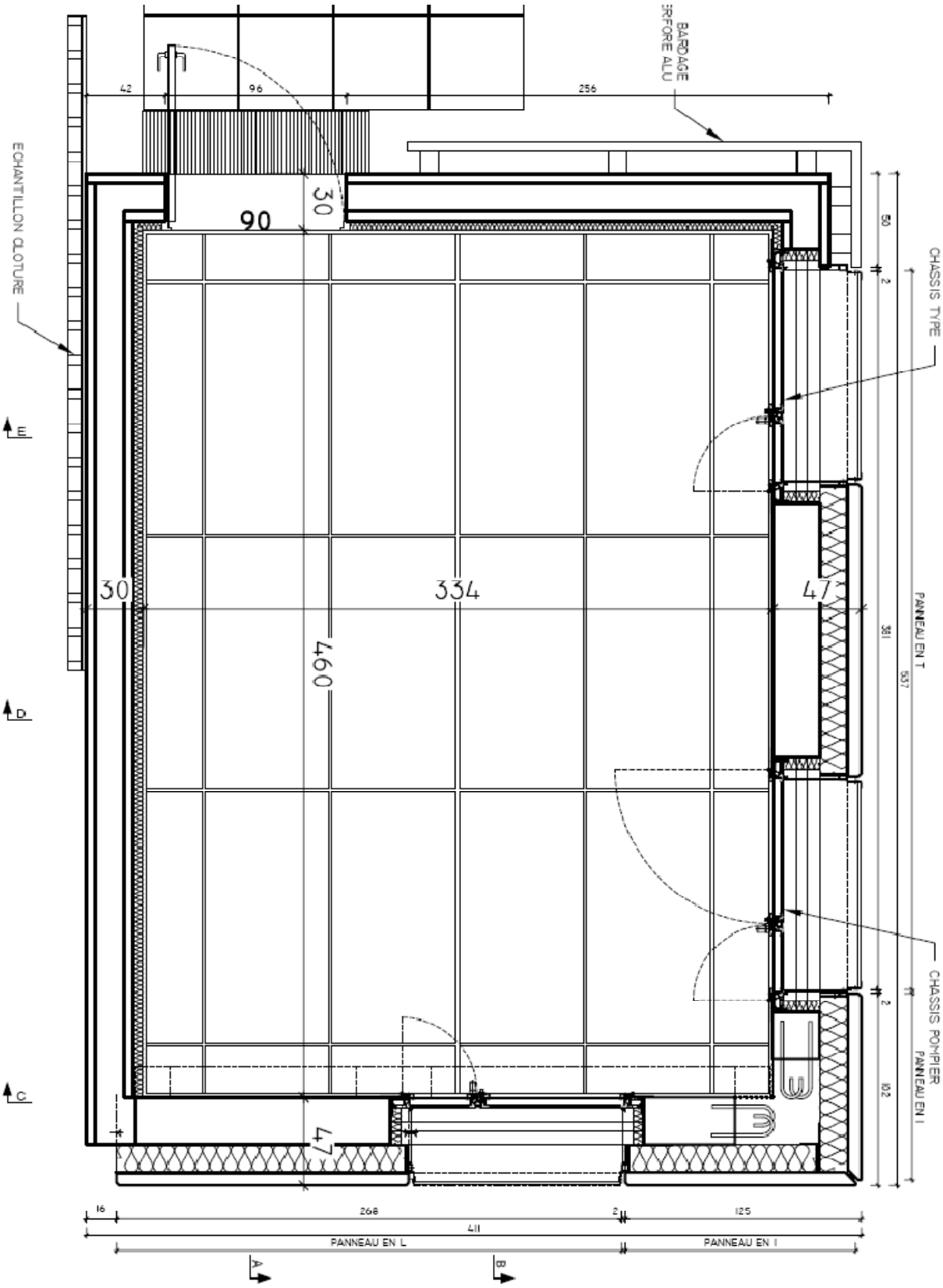


Annex 2 : Example of a sketch I had to check. Here, a regular T shape panel.

TABELL D1:4. Mättnadsånghalt (g/m^3) som funktion av temperaturen.

Temp (°C)	,0	,1	,2	,3	,4	,5	,6	,7	,8	,9
−20	0,81									
−19	0,86	0,85	0,84	0,84	0,83	0,82	0,81	0,80	0,80	0,79
−18	1,03	1,02	1,01	1,00	0,99	0,98	0,97	0,96	0,95	0,94
−17	1,16	1,15	1,14	1,12	1,11	1,10	1,09	1,08	1,07	1,06
−16	1,26	1,25	1,24	1,23	1,22	1,21	1,20	1,19	1,18	1,17
−15	1,38	1,37	1,35	1,34	1,33	1,32	1,31	1,30	1,29	1,28
−14	1,51	1,49	1,48	1,47	1,46	1,45	1,43	1,42	1,40	1,39
−13	1,65	1,63	1,62	1,61	1,59	1,58	1,56	1,54	1,53	1,52
−12	1,80	1,78	1,77	1,75	1,74	1,71	1,70	1,69	1,67	,66
−11	1,95	1,94	1,93	1,90	1,89	1,87	1,86	1,84	1,83	,81
−10	2,14	2,12	2,09	2,07	2,06	2,04	2,02	2,01	1,99	,98
− 9	2,31	2,29	2,28	2,26	2,24	2,22	2,21	2,19	2,17	2,15
− 8	2,52	2,50	2,48	2,46	2,44	2,42	2,40	2,38	2,36	2,34
− 7	2,74	2,72	2,70	2,68	2,66	2,63	2,61	2,59	2,57	2,54
− 6	2,99	2,96	2,93	2,91	2,89	2,86	2,84	2,82	2,79	2,76
− 5	3,24	3,21	3,19	3,16	3,14	3,10	3,08	3,05	3,03	3,00
− 4	3,52	3,49	3,46	3,42	3,40	3,37	3,34	3,32	3,29	3,26
− 3	3,80	3,78	3,75	3,72	3,69	3,66	3,63	3,60	3,57	3,54
− 2	4,13	4,10	4,06	4,03	4,00	3,97	3,94	3,91	3,88	3,84
− 1	4,48	4,44	4,41	4,36	4,33	4,29	4,26	4,23	4,19	4,16
− 0	4,86	4,80	4,76	4,73	4,69	4,66	4,63	4,59	4,55	4,51
0	4,84	4,87	4,81	4,84	4,87	5,01	5,04	5,08	5,11	5,15
1	5,19	5,22	5,26	5,29	5,33	5,37	5,40	5,44	5,48	5,52
2	5,55	5,59	5,63	5,67	5,71	5,75	5,78	5,82	5,86	5,90
3	5,94	5,98	6,02	6,07	6,11	6,15	6,19	6,23	6,27	6,32
4	6,36	6,40	6,45	6,48	6,52	6,57	6,61	6,66	6,70	6,75
5	6,79	6,84	6,88	6,93	6,98	7,02	7,07	7,12	7,16	7,20
6	7,25	7,30	7,35	7,40	7,45	7,50	7,55	7,60	7,64	7,69
7	7,74	7,78	7,15	7,90	7,95	8,00	8,06	8,10	8,16	8,21
8	8,26	8,32	8,37	8,42	8,48	8,53	8,59	8,65	8,70	8,76
9	8,81	8,87	8,53	8,99	9,04	9,09	9,15	9,21	9,28	9,34
10	9,40	9,45	9,21	9,57	9,64	9,69	9,75	9,82	9,88	9,95
11	10,00	10,07	10,14	10,20	10,26	10,33	10,39	10,46	10,52	10,59
12	10,66	10,72	10,79	10,86	10,93	10,99	11,06	11,13	11,19	11,27
13	11,34	11,40	11,48	11,55	11,62	11,69	11,77	11,84	11,91	11,99
14	12,06	12,13	12,20	12,28	12,36	12,43	12,51	12,59	12,66	12,75
15	12,82	12,90	12,97	13,06	13,14	13,21	13,29	13,37	13,46	13,54
16	13,62	13,70	13,79	13,87	13,96	14,04	14,13	14,21	14,30	14,38
17	14,47	14,55	14,64	14,73	14,82	14,91	14,99	15,09	15,17	15,27
18	15,36	15,44	15,54	15,63	15,73	15,82	15,91	16,01	16,10	16,19
19	16,30	16,39	16,48	16,59	16,68	16,78	16,88	16,98	17,08	17,18
20	17,28	17,38	17,48	17,58	17,69	17,79	17,90	18,00	18,10	18,22
21	18,33	18,43	18,53	18,63	18,74	18,86	18,97	19,08	19,19	19,30
22	19,41	19,52	19,63	19,74	19,85	19,97	20,08	20,20	20,32	20,44
23	20,56	20,69	20,80	20,92	21,04	21,15	21,27	21,39	21,51	21,63
24	21,76	21,89	22,00	22,13	22,26	22,38	22,51	22,64	22,77	22,90
25	23,03	23,15	23,28	23,41	23,54	23,66	23,80	23,94	24,08	24,21
30	30.4									
35	39.6									
40	51.2									
45	65.4									
50	83.0									

Annex 3 : Table of mass flows of saturated vapor



Annex 4 : Sketch of the prototype building