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Contact currents and biological effects on human beings

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Informative note

From June 2011, the BBEMG Montefiore team has changed. Jean-Louis Lilien is no more included in the team, to his own demand, based on deontological aspects linked to one of his new professional activities. The Management committee has been informed in due time and his colleague Christophe Geuzaine will take over the BBEMG duties after his departure (June 2011).

Contents

Introduction

The first study on magnetic fields and childhood leukaemia was done in the late seventies [Wertheimer N. & Leeper E., 1979]. Since then, some epidemiological studies put in evidence a (weak) correlation (Carcinogenic risk group 2B) between magnetic fields and childhood leukaemia. The threshold for this correlation was set to the value of 0.3 - 0.4 μT.

External magnetic fields induce very weak currents in biological tissues, which gives rise to a very low electric field (0.016 mV/m for an induction of 1 μT). Therefore, assuming that biological effects of magnetic fields are solely due to induced currents seems an inconsistent explanation. Indeed a minimum some tenths of mV/m (internal electric field), as stated by WHO, would be needed to potentially induce effects (not necessarily pathogenic).

Another hypothesis studied in the USA [Kavet R., 2000] considers an intermediate factor between magnetic fields and childhood leukaemia: the contact currents. These contact currents may induce an electric field of tenths of mV/m in the child bone marrow (for a realistic contact current value of a few microamperes) and without any sensitive reaction of the child. Besides, some correlation could also exist between the contact current level and the ambient electromagnetic field.

THE MAIN OBJECTIVE OF THE PREVIOUS PROJECT WAS TO REALIZE A CAMPAIGN ON BELGIAN RESIDENCES TO EVALUATE CONTACT CURRENTS LEVELS AND AT THE SAME TIME TO CHECK EARTHING AND TO MEASURE LOCAL AMBIENT FIELDS. IN THE CURRENT PROJECT, USING THE OBTAINED RESULTS, WE HAVE BEEN SEARCHING FOR A POSSIBLE CORRELATION BETWEEN THE CONTACT CURRENTS AND THE AMBIENT MAGNETIC FIELD.

A simple electric model of a human being has been developed to calculate the induced electric field by any external applied field or contact current, and to compare it with external studies. A comparison of 15 studies found in the literature has allowed us to somehow classify the influence of electric and magnetic field and contact current on the induced electric field in the bone marrow.

We also designed and constructed a device for injecting a current (1 mA max) in a forearm of a person. This device allows measuring the human body impedance of the people at 50 Hz for very low contact voltage (as we deal with in this study).

The four Main Tasks performed during this year.

Final result of the contact current campaign

A key aspect of our campaign was to understand the origin of these currents in the Belgian housing stock. Instead of a random sample, we preferred to measure (using a strict protocol) these contact currents for residences located near the lines, in order to obtain a statistical base to assess the potential correlation between the ambient magnetic field and contact currents. The main objective was to know if a relationship exists between these physical quantities.

Campaign to evaluate the origin of contact current

In view of the results obtained on the correlation between the ambient field and the contact currents, we have developed a new hypothesis (leakage current from electrical cables) able to justify the contact current level in residential houses. Measurements with a strict protocol have been performed to verify this new hypothesis, followed by computer simulations.

Simulation of the human body in a B and E field and subjected to a contact current

We are now able to calculate the induced electric field in the human body when a person is immersed in a B or E-field, using more realistic (finite element) models. We can also calculate the electric field when the body is subjected to a contact current. We were able to visualize the zones where the internal electric field reaches high value.

Evaluation of human body impedance

During the measurement campaign, we noticed that the human body is subjected to low potential differences (contact voltage). The body impedance in this range of magnitude of contact voltage is not well known. So we have decided to realize measures to know the impedance of the human body. Thanks to the previously developed numerical model we can also predict the human impedance by simulation.

Results

Results of the campaign

With the previous campaign we have now results of measurements in about 150 houses. We have measured the contact current principally where it could be important for humans, like in the bath, shower or near electrical applications (washing machine, …). For more details about the protocol we invite you to read the previous report (BBEMG report 2005-2009).

Magnetic field

In our measurement protocol, the magnetic field is measured in each room of the house. To have a good approximation of this field, the median value is chosen as the best estimator to dismiss high values that can be generated e.g. near micro wave ovens. The measurements are taken in the middle of the room at an average of 1,5 meter from the ground ; Figure 1 is showing such results.

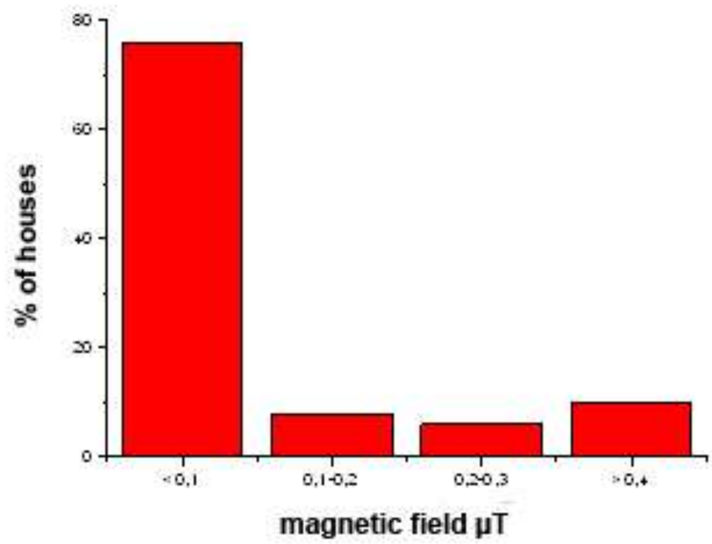


Figure 1: Magnetic field measurements.

The median value of our own spot measurement is 0,02 µT. We have 10% of visited houses with a magnetic field higher than the epidemiological threshold of 0,4µT. Our own measurements are close to the result of 24 exposure of children in Belgium (0, 02 µT) [Decat, 2009].

Contact current

We have visited about 150 houses, in which the contact current level varied from 1µA to 1000 µA. Some houses have contact currents higher than the threshold of sensitivity (Figure 2).

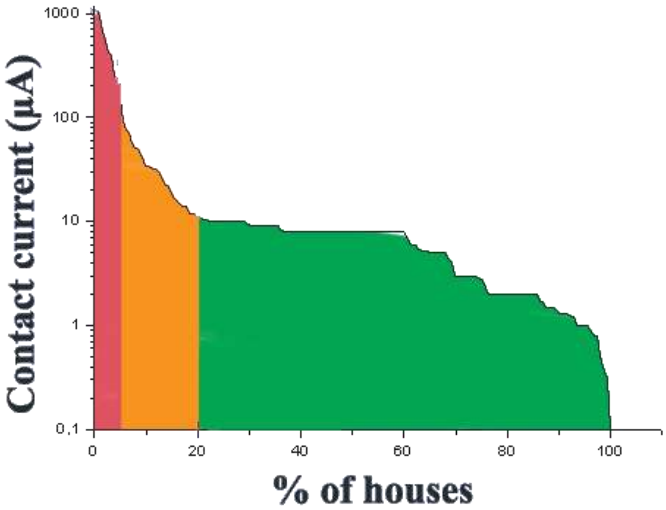


Figure 2: Contact current frequency graph.

- The median contact current of the frequency graph is 10 µA
- 80% of houses have contact current lower than 20 µA
- 20 % of houses have a contact current between 20 to 100µA
- 5% of houses have contact current higher than 100 µA

The contact current vs. relative number of house can be represented by a log – normal law. These kinds of laws are generally used in pollution cases [INRS, 2000]. Figure 3 shows the Belgian case.

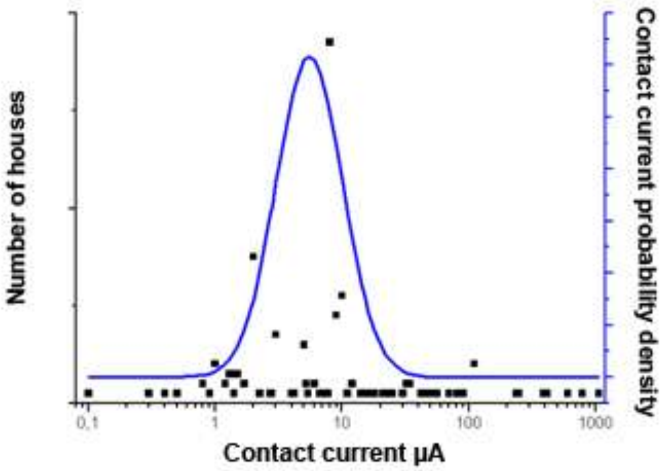


Figure 3: Log normal distribution.

We can consider that 5 % of Belgium houses have a very high contact current.

Measure of contact current in a « passive » house using shielded cables

We have realized measurements in a house that was built using specific cables (produced by Kabelwerk Eupen) to reduce the electromagnetic pollution at 50Hz or 60Hz.
The HF components of the electromagnetic field are absorbed by the conductor's ferrite coating (EMC/COM). Effective protection against 50 Hz or 60 Hz magnetic field is obtained through a very short length of twist; this considerably reduces the radiated magnetic field. The ferrite layer keeps this reduced magnetic field within the cable instead of allowing it to "break out". The cable static screen grants excellent protection against 50 or 60 Hz electric field.

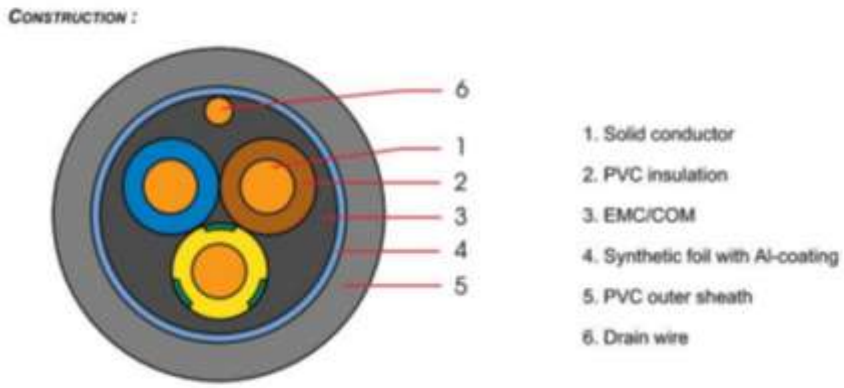


Figure 4 : Special cable.

We were not able to measure the contact current in this house. We suppose that the drain wire alone canceled the leakage current of the electrical wire. In this house we have however discovered that electrical appliances like the washing machine would generate a leakage current on the earth wire. The observation could be explained by RFI filters (also called EMI or "electromagnetic interference" filters) present in the appliances. Such filters are used to protect appliances from surges and interferences (such as parasites and electromagnetic radiation), which can affect the performance and longevity of appliances, but which do not come from "accidents such as lightning strikes. Refrigerators, air conditioners, irons with thermostat, boilers, halogen or fluorescent lamps, motors, cordless phones, are all potential sources of regular disturbances. Below is an example of such a filter (Figure 5: Low pass RFI filter).

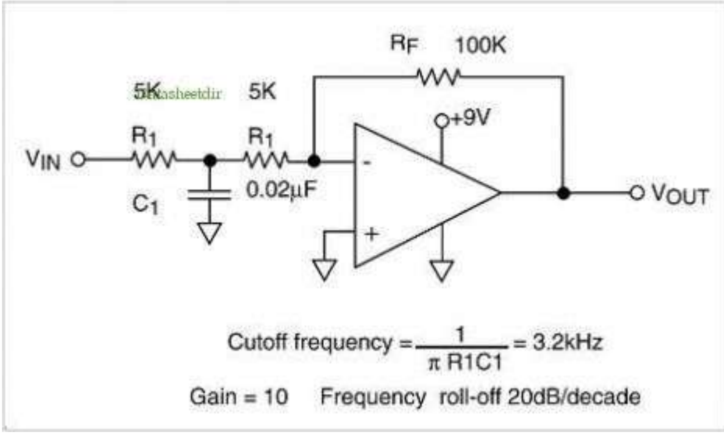


Figure 5: Low pass RFI filter.

Contact current and the magnetic field

Is there a correlation between contact currents and the residential magnetic field?
As shown in former reports, no relationship can be observed between contact currents and the ambient magnetic field: see Figure 6. On the same figure, the "simulated contact current" has been obtained by computer simulation taking into account external B field near 100 µT acting on a typical house equipped with a given cable distribution and typical earthing. That curve can then be considered as the part of contact current that could be induced by the external B field only. As Figure 6 is drawn using a log-log scale, the induced contact current (by B field) is negligible. All the measured values are very sensibly over that bottom line.

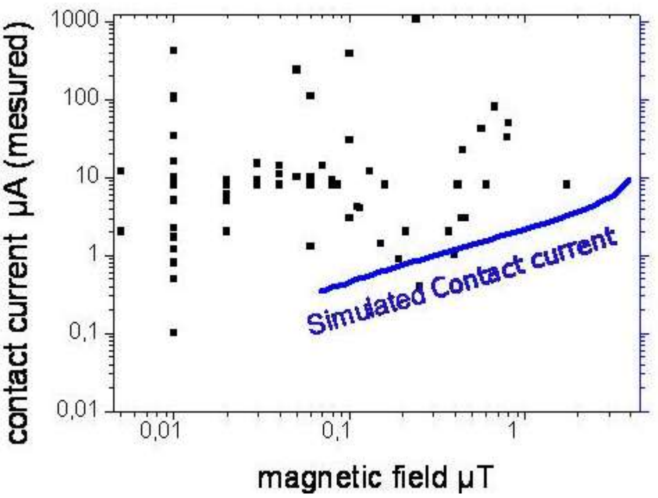
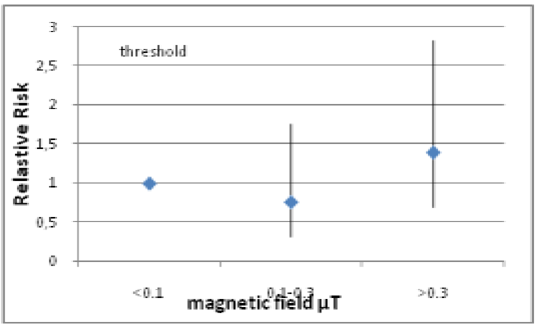


Figure 6 : Contact current versus ambient magnetic field.

The ambient magnetic field alone can thus not explain the measured values of contact currents.

In order to clarify this observation, we are showing in Figure 7 the odds ratio (OR) and relative risk (RR) of contact currents as a function of magnetic field in the Belgian residential park. For a threshold of 10µA, we observe that the OR is greater than 1 for magnetic fields above 0.3µT (Figure 7). This result is not significant because the lower bound of the confidence interval is below 1 and the number of measures in this category is relatively small. It has as much chance of seeing the phonemes insignificant than significant. The same trend is observed for a threshold of 100µA (Figure 7).



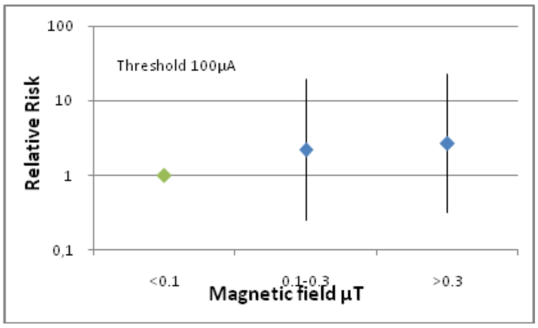


Figure 7: Relative risk in function of the magnetic field.

As the contact current could not be explained by the magnetic field, we have investigated another (new) hypothesis: the leakage current that exists by capacitive coupling between any cable and a reference potential area. Indeed most of residential electrical cables have no metallic screens and capacitive current may reach earth wire, as well as any metallic ducts like the ones used for water and gaz.

The Leakage current

Simulation and measurement of the leakage current

Houses usually contain hundreds of meters of electrical cable at 230 V (between phase and neutral wires). If cable radial divergent current (capacitive) could be of only a few µA/m, some metallic ducts in the vicinity could reach a certain voltage difference between each other.
We have estimated the leakage currents of electrical cables using three kinds of techniques: simple theoretical (analytical) formulas, laboratory measurements, and detailed numerical simulations. Theoretically, the leakage current of an electrical cable can be resistive and capacitive, but the resistive part will obviously be negligible for a cable of good quality.
To measure the leakage current of electrical cable at 230 volt, we tested an installation as shown on figure 8. An electrical cable is wind up with kitchen aluminum foil to recover the leakage current.

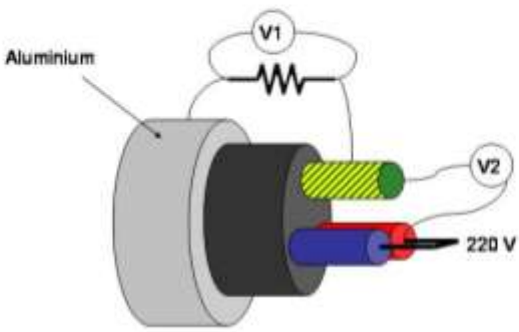


Figure 8: Experimentation.

We have used the finite element method to simulate the leakage current. The geometries and the boundary conditions are adapted to match the experimental measurements. Figure 8 shows the model of the cable realized with the Gmsh/GetDP software (a finite element software for electromagnetic simulation developed by the ACE team at Montefiore).

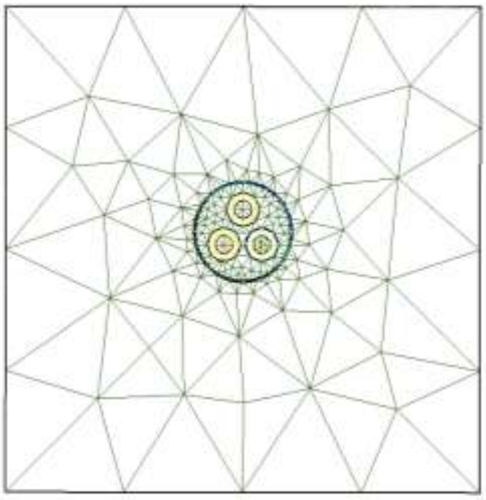


Figure 9: Mesh used for the numerical simulation.

The result of the study in summarized in the following table.

Cables	XVB 	VOB in a plastic duct 	VOB cable 
Theory	*6,85 μA/m*		*23 μA/m*
Measurement	*5,75 μA / m*		*13 μA/m*
Simulation	*6,82μA/m*	*2,89μA/m*	*10,5 μA/m*

During on site measurements we have decided to measure phase shift between the contact voltage and the voltage of the house. If we have capacitive impedance, the phase difference should be 90°. In a lot of visited houses we have obtained this kind of result (Figure 10). To measure this phase shift, we have used a double trace scope. One channel was used for the home voltage and the second for the contact voltage.

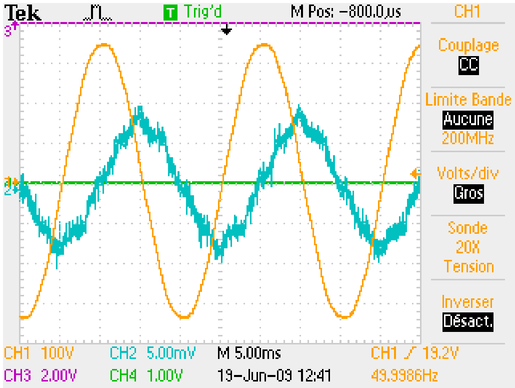


Figure 10: On site shift measurement.

Campaign measurement of the leakage current

In order to justify our hypothesis, we have carried out a test campaign in an actual domestic house. To highlight these capacitive effects, we connected an electrical line of the house on a voltage generator. To find the line that generates the largest contact voltage we switched off the circuit breakers one by one in the electrical panel. Then we switched on a second electrical line to connect the generator (Figure 11).

Figure 11 : site measurement

Then the line was put at different voltages to see if the contact voltage ranges were of the same order of magnitude. The voltages selected for the measurements were 110, 220 and 300V at 50 Hz. Following Ohm's law, we should have a linear relationship with the voltage variation (Figure 12).

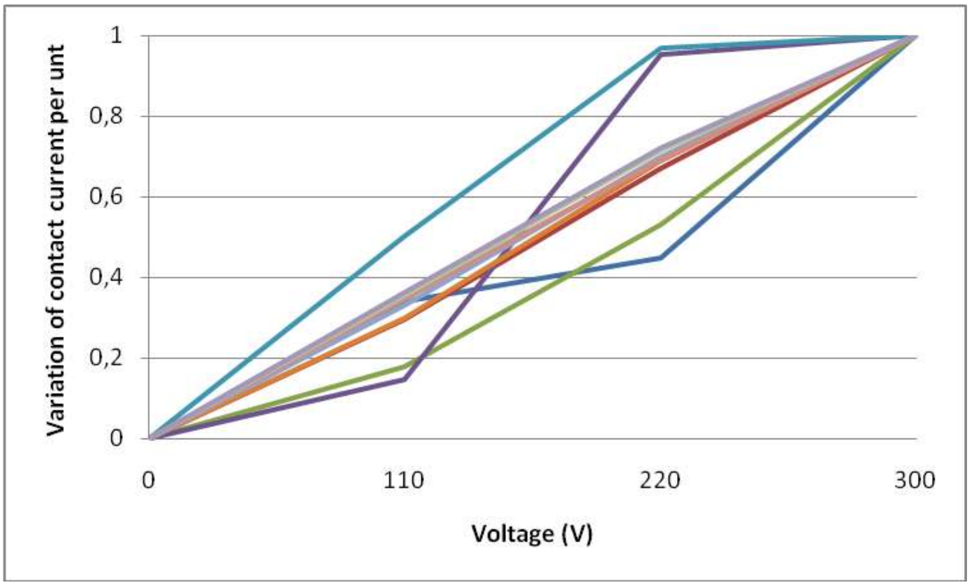


Figure 12: variation of contact current with respect to the applied voltage applied.

In our case, if the contact currents are mainly capacitive; the capacitive impedance being defined as:

$$Z_C = \frac{1}{j\omega C}$$

by increasing the frequency, we would reduce the capacitive impedance. We used different voltages of 110, 220 and 300V. For each voltage, we measured the contact currents for different frequencies: 0, 50, 100 and 150 Hz. We should normally observe a linear increase of the contact voltage (**Figure 13**).

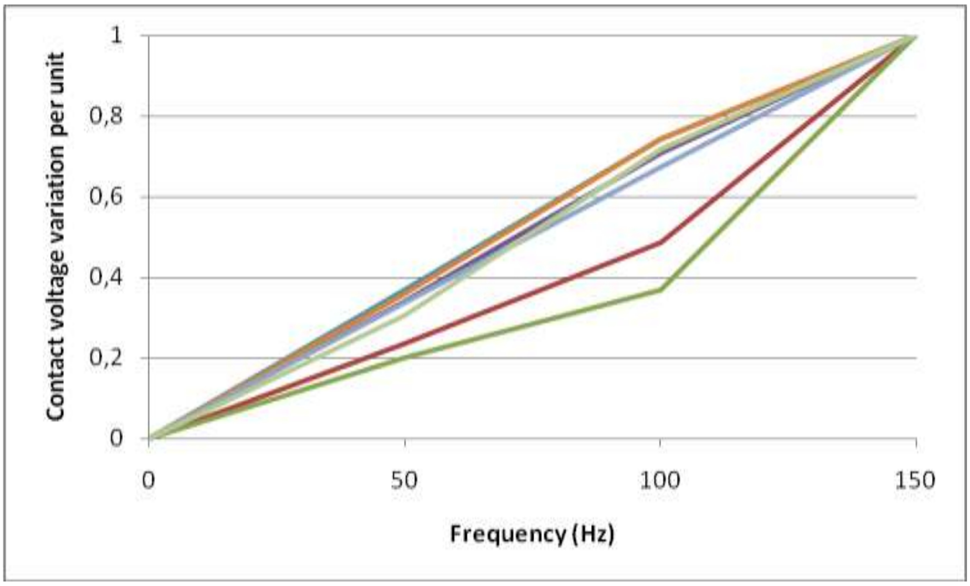


Figure 13: Experimental measurements.

This last investigation confirms the hypothesis that the contact current is due to a capacitive effect in the house and not due to the presence of magnetic field in the vicinity of the house.

Simulation of the leakage current

In order to illustrate how the contact currents are created we can consider the electric model show in Figure 14.

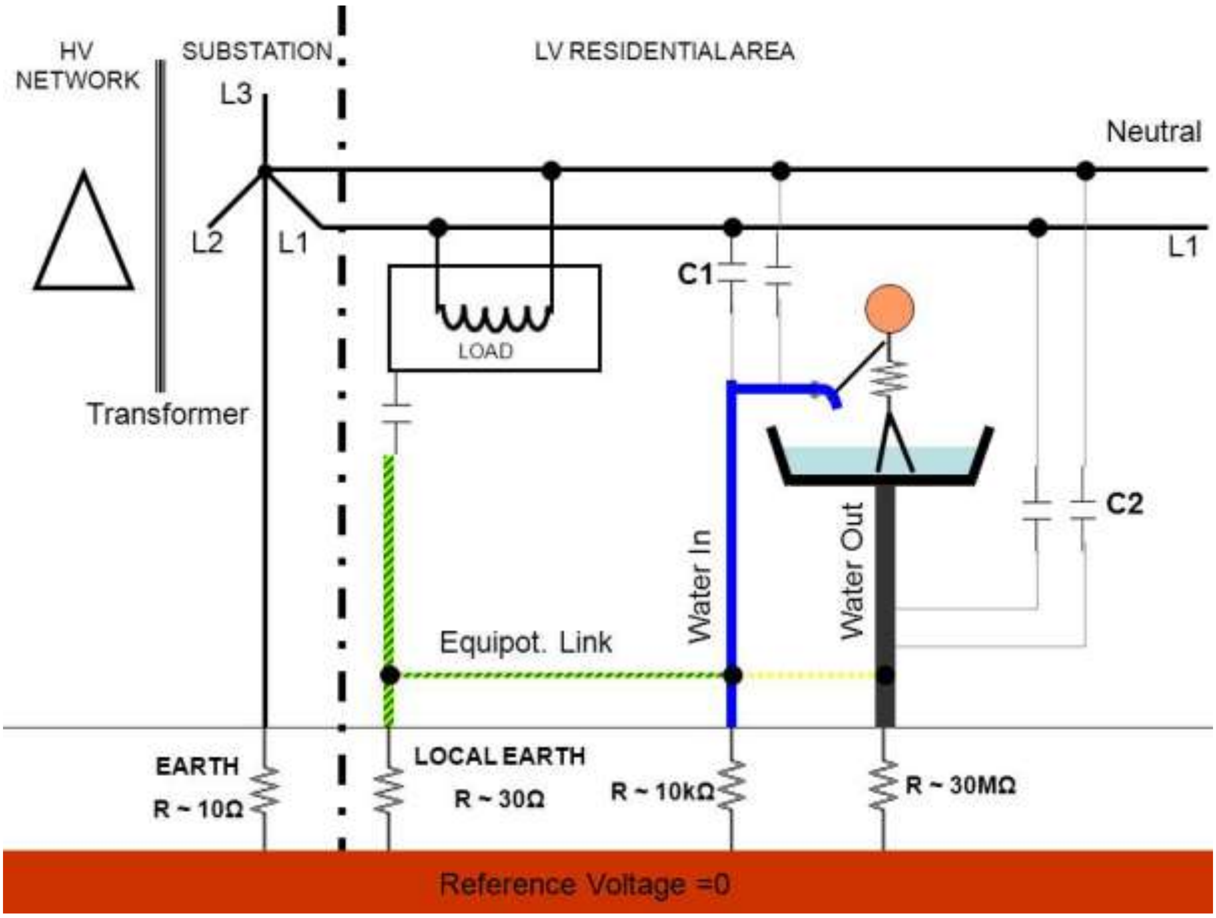


Figure 14: Model

From the transformer, a phase and neutral are routed into the house by air or by ground. Once in the house, the neutral and phase are distributed throughout the house to supply electrical charge. We have an earth resistance of 30Ω maximum.
The question is how to justify the values of resistances used in the model. The earth resistance of the house and the transformer are regulated and are therefore easy to estimate. They vary from 1-30 Ohms. And they can be easily measured. Grounding resistance of the water meter is measured as the earthling of the house.
To evaluate the value of the capacity we realized a measurement. We know that the origin of the contact currents comes from the electrical cable in the house (the 220 V). We thus simply measure the current that flows to earth with the help of a pole planted outside. Then using Ohm's law, we can calculate the capacitance.

Then we take the same measures with the drain. Once all the values known, we can calculate the contact current with the help of our diagram.
Now we can simulate our circuit (Figure 15):

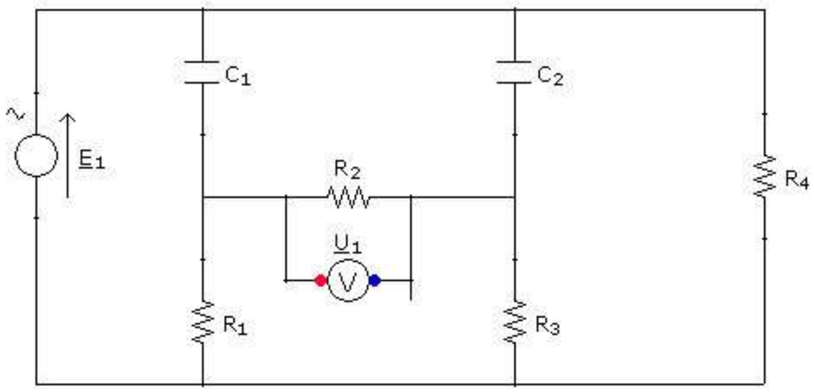


Figure 15: Electrical simulation.

	E1	C1	R1	R2		C2	R3	R4
Description	Home tension	Capacity between electric cable and	Earth resistance	Human body impedance	Contact tension	Capacity between electric cable and water	Water out earth resistance	charge
Value	220 V	325 nF	30 Ω	1kΩ	7 mV	100pF	3MΩ	1kΩ

Thanks to the circuit, We are now able to calculate the phase shift and the value of the contact voltages.

$$U_1 = \frac{R_2E_1(R_1C_1 - R_3C_2)}{R_1R_2C_1 + R_1R_3C_1 + R_1R_2C_2 + R_2R_3C_2 - j\left(R_1R_2R_3C_1C_2\omega + \frac{R_1}{\omega} + \frac{R_2}{\omega} + \frac{R_3}{\omega}\right)}$$

$$U_{1eff} = \frac{|R_2E_{1eff}(R_1C_1 - R_3C_2)|}{\sqrt{(R_1R_2C_1 + R_1R_3C_1 + R_1R_2C_2 + R_2R_3C_2)^2 + \left(-R_1R_2R_3C_1C_2\omega + \frac{R_1}{\omega} + \frac{R_2}{\omega} + \frac{R_3}{\omega}\right)^2}}$$

Applying that formula with the mean value obtained during the campaign we obtain an average contact current of 7mV and a phase shift of 90.2° in accordance with the campaign result.
The phase shift could also be calculated: Figure 16 compares the site measurement and the simulation.

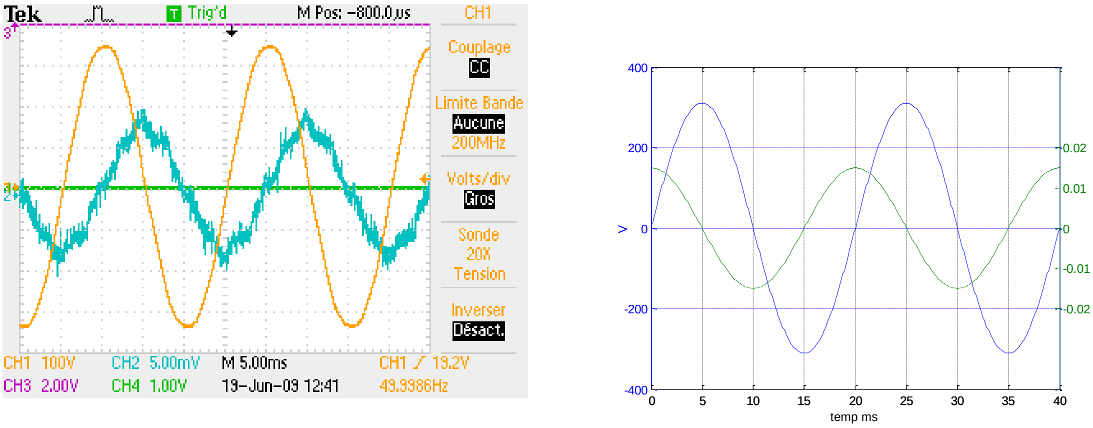


Figure 16: Experimental measurements (left) and simulation (right).

Simulation of the human body in a B and E field and subjected to a contact current

In this section we present the results of the calculation of the internal electric field from three different external sources (E-field, B-field and the contact current).
We have chosen the intensities for these sources from standards for the E and B field. The values extracted from the standards are an electric field of 10kV/m, a magnetic field of 100 µT and we have chosen a contact voltage of 10 mV. This voltage is applied between the right forearm and the left foot to avoid the heart.
We have used the same software tools as the one we used for computing the leakage currents from cables, namely the GetDP/Gmsh finite element code developed by the ACE team. To compute the internal electric field of a body subjected to the three aforementioned external sources, the software solves Maxwell's equation in the quasistatic regime.
The model used for the simulation is a man of 38 years. His name is Joseph Paul Jernigan; he was sentenced to death in the US. With the suggestion of the prison chaplain, Joseph decided to give his body to science. His body, after a lethal injection, has been frozen and then cut in slices 1 mm thick, digitized in 3D for use in scientific calculations. The original dataset is available free of charge on the following web site: http://visiblehuman.epfl.ch/index.php .
The human body mesh is composed of the most important organs. The permittivity and the conductivity of those organs came from the Institute of Applied Physics in Florence.
The following graphs present the solution for different sources. Figures 17 shows the internal electric field in the body subjected to a voltage drop of 10 mV between an arm and a foot. Figure 18 shows the internal electric field in the body subjected to an external magnetic field of 100µT. Figure 19 shows the internal electric field in the body subjected to an external electric field of 10 kV/m.

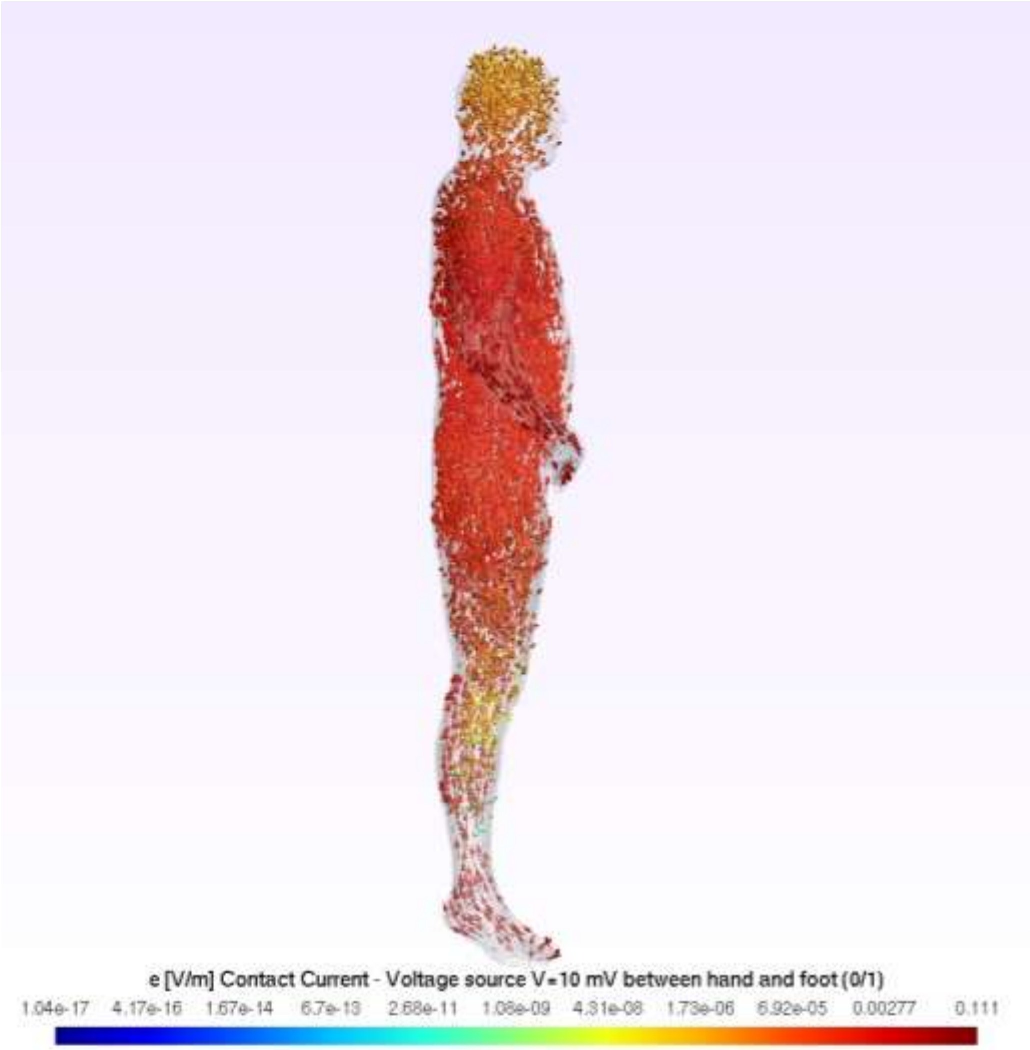


Figure 16: human body subjected to a different voltage of 10 mV between arm and foot

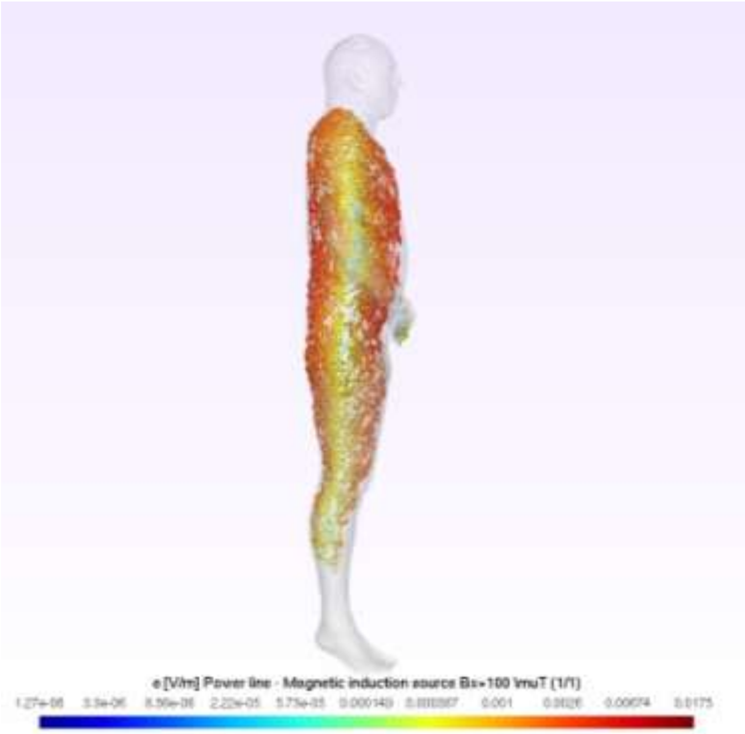


Figure 17: human body subjected to a magnetic field of 100µT.

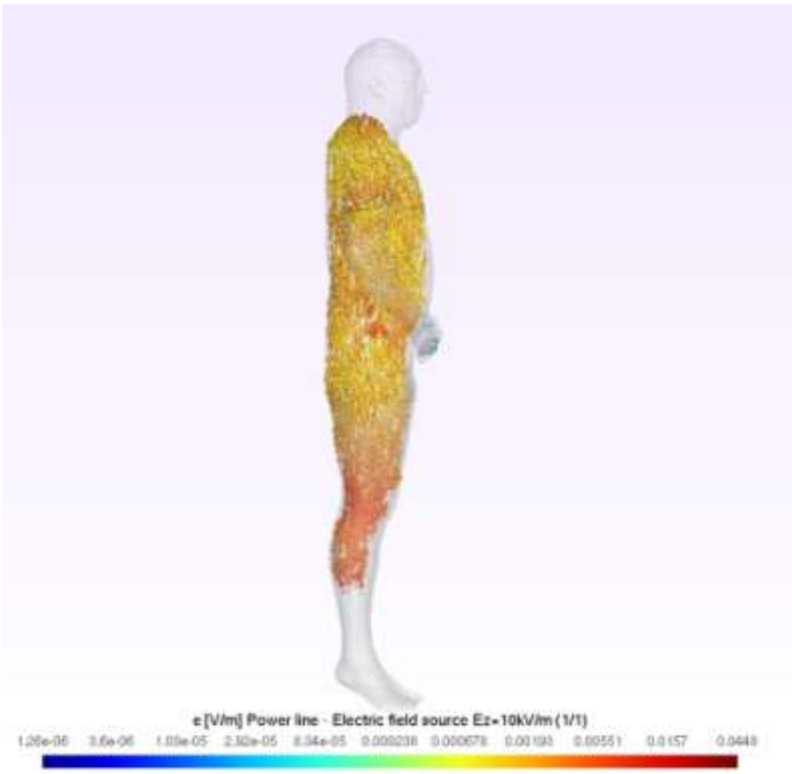


Figure 18: human body subjected to a electric field of 10 kV/m.

A comparison of the zones of the body with an internal electric field higher than 1 mV/m is provided in Figure 19.

B field of 100µT	Electric field of 10 kV	Voltage difference 10mV

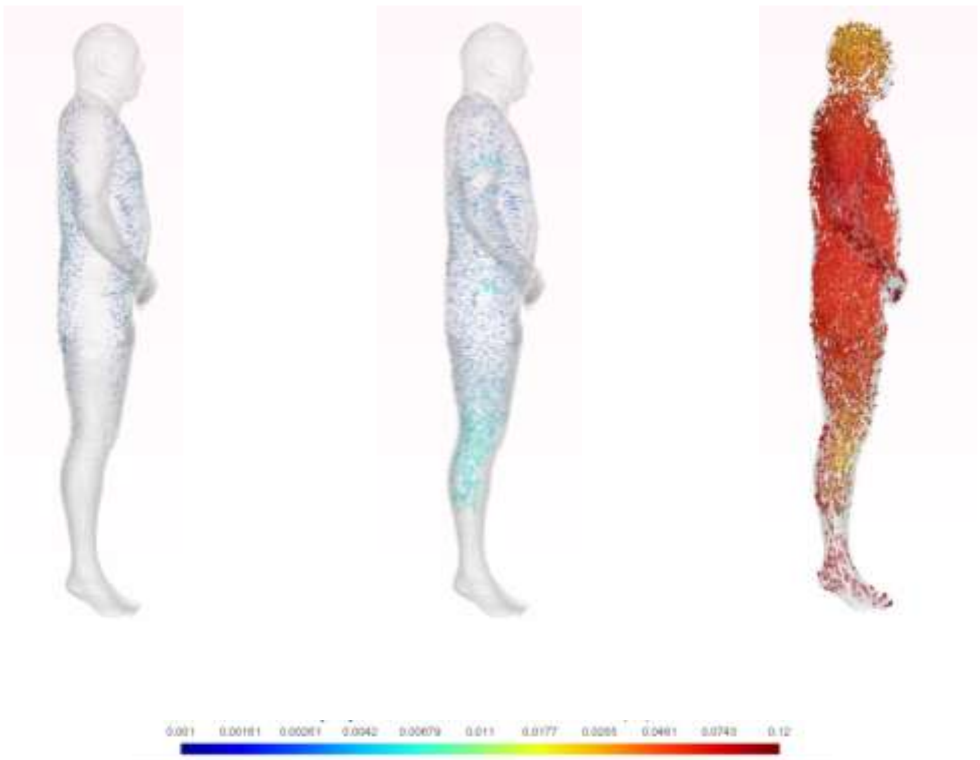


Figure 19: Internal electric field higher than 1mV.

We note that a contact current admissible with typical standards generates a higher internal electric field than the exposure to external electromagnetic fields. If we look at only those physical quantities, it is thus imperative to consider the contact currents as more potentially harmful than the electromagnetic fields.

Human body impedance

The knowledge of the human body impedance is important as it is used in our contact current measurement protocol. This impedance is well known for voltages ranging from 25 to 1000V but results for voltages under 25V are nonexistent..

In our measurement protocol (see previous report) the use of the impedance simulating the human body in the bathroom was 1kohm. This value was not arbitrary and corresponds to the U.S. standard.

However the impedance of the human body is not a constant; it varies from one person to another and depends on its state of moisture, stress.... (IEC 61201, TS, Ed 2). The impedance as the electrical sensitivity is specific to each person. When someone is subjected to a contact current he usually cannot feel it, because the value is below the threshold of perception. The current perception threshold is located in the neighborhood of 500µA (Leitgeb, 2003), a value also obtained during the measurement campaign conducted at the ULG (DEA Brice Mattivi).

In order to measure the human body impedance we have injected a current through the body and we have measured the voltage between the two electrodes. Then applying Ohm's law, we were able to calculate the human body impedance.

The experimental setup consists of a power supply unit, a power injector and electrodes. The principle of our injector is to use the computer's sound card to create a 50 Hz signal and send it to the injector. The 50 Hz signal is sent through the human body and thanks to the electronic device (detailed in a previous report), allows us to have a constant current flowing through the body.
Once the machine is well calibrated, we can start our measurements. Our measurements are taken between the right forearm and left leg to avoid the heart (Figure 20).

Figure 20: experimental device

The current intensities were chosen based on the results of the measurement campaign. So we will submit people to currents between 25µA and 600µA.
The different steps for the currents are 25, 50 100, 140, 200, 250, 300, 350, 400, 500 and 600 µA. The experiments are performed in a sitting position to avoid too many disconnections due to movements.
Once the experimenter is ready, we wait that the voltage stabilizes and let us take note of this one. Then a short pause is taken before submitting the person to a second value. With voltages measured and value of the injected current, we can find the impedance of the human body. Before each experiment, the electrodes are changed and coated with conductive gel.
During the experiments, some people are more sensitive than others. In this case, the tests are stopped earlier.
The campaign of impedance measurements was conducted among 30 young people aged 19 to 25 years. The results are the following (Figure 21).

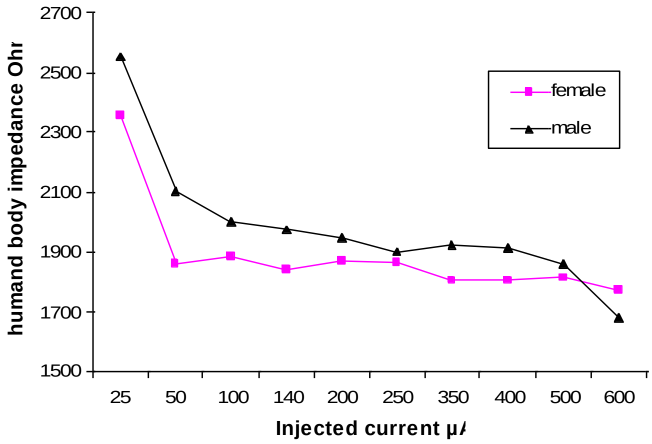


Figure 21: Measure of the human body impedance

To have a point of comparison, the current flow 600µA through the body with impedance of 1800Ω give us a contact voltage of 1V.

Conclusion

After a data collection of contact currents for a period of 5 years we have now lots of measurements (about 150 houses). In our database, the percentage of houses with an ambient magnetic field higher than 0.4 µT is about 10 %. (Our database has not to be considered as an average of Belgium houses in general because we decided to choose houses as close as possible to electrical power lines.)
With such a database, we have not found any correlation between the ambient magnetic field and the contact current.
Another explanation of the origin of contact current has thus been developed: "the leakage capacitive current from electrical in house cables". That current has a phase shift of 90° with the house main voltage. After simulations and measurements (at different voltages and different frequencies) we proposed a model able to justify the level of observed contact current in Belgian houses. As each house has different cable configuration and different proximity with metallic ducts, the contact current is different in each house but near 10 µA as an average can indeed be justified, with particular situations which may generate up to 100 µA contact currents.
As mentioned in many new reports from different organisms (WHO, ICNIRP) it is more realistic to mainly look at the internal (to the body) electric field to start discussions about potential biological effects.
We thus performed (finite element) simulations on a human body, to once again put into evidence that a 100 µA contact current gives an internal electric field much more important than the ones that could be reached by external application of typical (but high) 50 Hz magnetic (100 µT) or electric field (10 kV/m) below power lines.
Last but not least, we have evaluated with our own test system, the human body impedance at very low contact voltage. We have found that when the human body is subject to low contact current his own impedance does not

exceed a value of 3000 Ohms, rather compatible with the impedance used for higher voltages.
As a final conclusion, if internal electric field is indeed the parameter to consider for biological concerns into human body, contact current is the main potential source of high internal electric fields. The effect from fields generated by power lines in that regard is much smaller.
As the contact current origin is clearly demonstrated to come from capacitive current leakage for typical domestic cables, it is recommended to use domestic cables with metallic drain to avoid these leaks. Coupled with appropriate earthing, that would certainly eliminate that potential source of concern for human beings.

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Summary

A large campaign of measurement on 150 Belgian houses has been performed during the project.
If internal electric field is indeed the parameter to consider for biological concerns into human body, contact current is the main potential source of high internal electric fields. The effect from fields generated by power lines in that regard is much smaller.
The contact current originates from capacitive current leakage for typical domestic cables. It is thus recommended to use domestic cable with metallic drain to avoid these leaks. Coupled with appropriate earthing, that would certainly eliminate that potential source of concern for human beings.